**Drivers of scientific success; an analysis of terrestrial magnetism on the *Discovery* Antarctic expedition, 1901-04.**

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A thesis submitted in partial fulfilment of the requirements for the Degree

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by Andrew James Atkin

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Statement of Authorship/ Originality

I certify that the work in this thesis has not been previously submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Signature of Candidate

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**Contents**

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# Abstract

The turn of the twentieth century was an era of intense exploratory and scientific activity on and around the Antarctic continent. A few campaigns specialised in either territorial discovery or scientific inquiry, but most combined exploration and science in a comfortable alliance that produced results in both arenas. In recent years the scientific achievements of the *Discovery* expedition (1901-04) have been the subject of renewed analysis, but it is never clear what criteria, if any, are being applied to support statements about scientific success.

This research is founded on a case study focused on the magnetic science program of the *Discovery* expedition commencing with preparations, performance of magnetic observing at sea and ashore, post-expedition management of the products of research, and finally, arrangements for publication. The case study forms the basis for firstly, identifying the indicators of scientific success and secondly, an analysis of the relative contributions of the drivers promoting quality scientific outcomes during the era of Antarctic scientific exploration between 1898 and 1914.

The principal elements contributing to superior outcomes are identified as the human elements of preparation, leadership, scientific practice, skill, knowledge development and finally post-expedition management of data or collections gathered during fieldwork. No single element guarantees scientific success; it is a product of a combination of factors, but failure in just one facet can undermine outcomes fatally. The effectiveness of the relationship between these factors determines the degree of success or failure of a program. Achieving the potential of a research program relies on elements coming together in a timely and synergistic manner in combination with a measure of luck.

There was confusion between the magnetic work intended to provide improved charts for navigation purposes and the scientific research designed to help solve the causes of terrestrial magnetism and it's effects. The magnetic work of the expedition was divided into three distinct operations. Firstly, observations were made at sea in the ship's purpose built magnetic observatory and using a recently developed instrument for the determination of magnetic dip and force. The results were ultimately never published due to the inadequacy of the instrument and the difficulties of taking reliable observations at sea. Secondly, a fixed observatory was established at the base station in Antarctica where a different set of instruments recorded the magnetic elements almost continuously over the two-year stay of the expedition. There was sufficient data from those observations to form the core of the

scientific reports on terrestrial magnetism, but large amounts of data were considered unreliable and either discarded, or included with cautionary notes. Thirdly, magnetic observations made on exploratory sledging journeys away from the ice station added evidence for theoretical determination of the location of the South Magnetic Pole and for mapping the lines of equal magnetic declination radiating from it. The conclusions from these journeys were brought into doubt by evidence from later expeditions.

During fund raising and promotion of the expedition, Sir Clements Markham, President of the Royal Geographical Society stated firstly, that products of the magnetic research would include new magnetic charts of value to mariners and secondly, there would be significant leaps in knowledge informing magnetic theory. These were ambitious objectives and neither were realised, although the data collected did add to knowledge of the characteristic fluctuations of the magnetic field at high latitudes. Collaborative arrangements planned between the *Discovery*, the German *Gauss* expedition and various established land observatories never reached their potential. This was partly due to an error in the timing of synchronous observations, but mainly a result of collapse of the intended post-expedition data sharing arrangements related to rejection by the Germans of the unreliable data from *Discovery* and failure by the English to publish data in a mutually useful format.

The thesis closes with analysis of how well the *Discovery's* outcomes matched their potential and concludes that, with respect to magnetic science, institutional failures led to avoidable deficiencies in areas of recruitment, training, governance and leadership, procedures, instrumentation and post-expedition management of data and publication preparations.

# Glossary

| Title | Initials |
|---|---|
| Australasian Antarctic Expedition (*Aurora*), 1911-1914 | AAE |
| Australian Antarctic Territory | AAT |
| British Antarctic Expedition (*Southern Cross*), 1898-1900 | BAE |
| British, Australian and New Zealand Antarctic Research Expedition (1929-1931) | BANZARE |
| British Museum of Natural History | BMNH |
| British National Antarctic Expedition (*Discovery*), 1901-1904 | BNAE |
| Greenwich Mean Time | GMT |
| International Geophysical Year | IGY |
| Royal Geographical Society | RGS |
| Royal Navy | RN |
| Royal Society | RS |
| Royal Scottish Geographical Society | RSGS |
| Scientific Committee on Antarctic Research | SCAR |
| Scott Polar Research Institute (Cambridge) | SPRI |
| United Kingdom Hydrographic Office | UKHO |

# Tables and Figures

# Images

# Chapter 1: Introduction

In the April 1901 volume of *Nature* Professor John Walter Gregory (1864-1932) broadcast a provisional summary of the program for the British National Antarctic Expedition (BNAE) that later became known as the *Discovery* expedition. As the civilian director of the scientific staff of the expedition, and leader of the overwintering shore party, Gregory anticipated a full scientific program in the natural and physical sciences with research into terrestrial magnetism the top priority. This expedition was one element of an International scientific effort in magnetic science and was the largest scientific campaign of its day. Gregory described terrestrial magnetism as: "the object of primary importance" (Gregory 1901c)[1]. As a professor of geology with abundant expedition experience, including the first crossing of Spitzbergen with Sir Martin Conway (1856-1937), Gregory was a suitable choice as a leader for the forthcoming Antarctic expedition. The expedition was well funded and had the patronage and guidance of the Royal Navy (RN), the Royal Society (RS) and the Royal Geographical Society (RGS), as well as funding from government and philanthropists. The expedition ship under construction was a purpose built, ice-capable floating magnetic and marine science laboratory. A mix of competent and enthusiastic civilian scientists and trained RN officers would undertake the scientific program. Prospects for the expedition were bright. Then, just two months later, the same journal published a short letter from Gregory announcing his resignation. He wrote:

> The organisation of the expedition now leaves the head of the civilian scientific staff nominally responsible for most of the scientific work of the expedition but gives him no power to secure the performance of the scientific part of the programme.
>
> (Gregory, 1901d)

How did this come about and what were the consequences for the scientific program?

[1] Quotations and documents reproduced in appendices retain the spelling, punctuation and layout from original documents throughout this thesis.

Science had been subordinated to other objectives, and leadership of the expedition passed to Lieutenant Robert Falcon Scott (1868-1912), a RN career officer. The expedition proceeded with Scott as expedition leader, commander of the vessel and in effect, head of the civilian scientific party. The enterprise achieved more than three full years of intense exploration and scientific work between 1901 and 1904 and contemporary accounts and modern reflections generally agree the expedition was highly successful, but it is often unclear whether this refers to the exploration, science or both. This thesis examines the question of whether the *Discovery* expedition's scientific program genuinely achieved all it could, and should have, considering the favourable circumstances of its preparation. By analysis of the drivers of scientific success for early Antarctic expedition science, and by separating the scientific from exploratory outcomes, this thesis ultimately provides informed commentary on how well the scientific outcomes matched the expectations of sponsors.

## 1.1 Context and scope

The scientific discovery of Antarctica proceeded in a sporadic manner. The circumnavigation of high southern latitudes by James Cook's (1728-1779) *Resolution* and *Adventure* expedition (1772-75) and Fabian Gottlieb von Bellingshausen's (1778-1852) *Vostok* and *Mirny* (1819-21) proved the capability of square rigged sailing vessels to cross the Antarctic circle into the zone of icebergs, and demonstrated there were open seas in hitherto unsuspected regions. Cook correctly predicted the existence of a significant landmass further to the South. He predicted that an Antarctic continent would lie mostly within the Antarctic Circle, was protected by a fringe of sea ice dangerous to navigation and that it was a land of thick fogs, snowstorms and intense cold. In his journal of Monday 6 February 1775, he argued that the massive tabular icebergs that he called "Ice mountains" could only have been created on, or by land (Beaglehole, 1961, p. 637). Three significant expeditions took place between 1837 and 1843, each locating and mapping sections of the coastline of continental Antarctica. The

French naval expedition of Captain Jules Sébastien César Dumont d'Urville (1790-1842) located the coastline in a region of Adélie Land, an area almost due South of Hobart (d'Urville, 1987, p. 469). Two of the ships from Commander Charles Wilkes' (1798-1877) 'United States Exploring Expedition', the *Flying Fish* and *Peacock*, also found the coastline near the same region then followed it in a westerly direction. They mapped what appeared to be segments of more than 2000 kilometres of coastline (Philbrick, 2004, p. 333). The third voyage of exploration of the era was the British Naval Expedition of Captain (later Sir) James Clark Ross (1800-1862) in the ships *Erebus* and *Terror*. Ross, like D'Urville and Wilkes was able to navigate his ships through the protective fringe of sea ice but had the good fortune to chance upon a large indentation in the Antarctic coast. He sailed his ships through the pack ice and into the open sea now named for him. He followed the coastline south and mapped over six and a half degrees of coastline (about 700 kilometres) before ice conditions halted his progress (Ross, 1847, pp. 415-417). He discovered Ross Island, which was to become the hub of Antarctic exploration and science, and named its two volcanoes after his ships. Then, at his southernmost point, Ross discovered a feature new to science, an ice shelf up to sixty metres high, which he called "The Great Ice Barrier."

These voyages of discovery proved the existence of a significant Antarctic landmass, or an archipelago welded together by an ice sheet, and proved the capability of ships to penetrate the ring of fringing sea ice. From the scientific perspective their most important achievement was their work advancing knowledge of the location and characteristics of the south magnetic pole. All three expeditions had research into terrestrial magnetism in their instructions. Ross who had previously located the north magnetic pole in 1831, had particular magnetic science credentials and his specific mission was to locate its southern equivalent.

After 1843 there was a thirty-year break in official interest in high southern latitudes. Charles Wyville Thompson's (1830–1882) HMS *Challenger* expedition of 1872 to 1876 concentrated on benthic marine science and oceanography, so did not approach the Antarctic coastline although, as the first scientific research vessel with steam power to cross the Antarctic Circle, it was more ice capable than any preceding vessel in high southern latitudes. The *Challenger* expedition was also notable for innovative oceanographic research techniques and is considered the first Antarctic expedition with purely scientific, as opposed to mixed navigational or colonial aims (Conrad, 1999, p. 67). There was a break of twenty years before renewed interest in Antarctica resulted in fifteen significant exploring and scientific expeditions between 1897 and 1916. The historian J. Gordon Hayes coined the phrase "Heroic Era" to describe the period from 1906 to 1914. He justifies it thus:

> The footsteps of the British explorers were continually dogged by disaster and some of them purchased their discoveries with their lives. As a small tribute to these gallant men it is suggested that this period should be known as the Heroic Era of Antarctic Exploration.
>
> (Hayes, 1932, pp. 29-30)

This expression is now in common use by polar historians, authors and commentators and is recognised by the reading public. It is often expanded in scope to describe the period from 1897 to 1922, the year Ernest Shackleton (1874-1922) died, but the use of the phrase "Heroic Era", obscures the significance of the scientific activity of expeditions of the time, and the contributions of nations besides Britain. During this period of scientific reconnaissance, some of the expeditions of the era (listed at Appendix I) had scientific research as their main purpose, *Scotia* and *Aurora* for example, but most, like *Discovery*, mixed science with exploration. During this period, further sections of Antarctica's coastline were discovered and mapped, the first inland traverses were made and a broad range of physical and natural scientific investigation was undertaken.

The intense period of activity of scientific reconnaissance between 1897 and 1914 was a period of transition when the status of science began to match exploration in Antarctic expedition objectives, and the manner in which scientific activities were planned and executed was elevated to a new level of professional practice. The focus of this thesis is an investigation of the drivers of scientific success on expeditions such as these. An in-depth case study of the research program into terrestrial magnetism on the *Discovery* expedition 1901-04 serves as a lens through which the factors regulating scientific outcomes are dissected.

## 1.2 A new era of Antarctic exploration and science

Despite the success of Ross's Antarctic campaign of 1839-1841, the RN switched its polar attention to the Arctic. There was a mercantile incentive to solve the riddle of the North West passage that could provide a navigable route across the top of Canada from Hudson Bay to the Bering Strait (Berton, 1988, p. 16). The same ships used by Ross in the Antarctic (HMS *Erebus* and HMS *Terror*) were fitted with modest steam engines and called into service again for an attempt on the passage by Sir John Franklin (1786-1847). The expedition became confounded in the maze of ice bound islands precipitating more than fifty search expeditions before the fate of the expedition was known with certainty (Berton, 1988, p. 151).

In the meantime Professor Georg von Neumayer (1826-1909), a German physicist and geomagnetic specialist in Australia promoted the idea of southern hemisphere terrestrial magnetic science. He was director of the astronomical and magnetic observatory in Melbourne (Flagstaff Observatory) whose establishment in 1858 had been partly funded by Maximilian II of Bavaria (1811-1864). Neumayer returned to Germany in 1864 and "became a tireless promoter of exploration in the Antarctic" (Murphy, 2002, p. 66). Sir John Murray (1841-1914), of the HMS *Challenger* expedition was another influential figure and a keen lobbyist for a return to the Antarctic. He lectured to the RGS meeting in November 1893 in London, and his arguments in favour of renewing Antarctic exploration were reported in the society's journal, along with those of a selection of eminent scientists and geographers whose views he canvassed prior to the meeting. On the topic of terrestrial magnetism, Murray quoted Neumayer: “It is certain that without an examination and a survey of the magnetic properties of the Antarctic regions, it is utterly hopeless to strive, with prospects of success, at the advancement of the theory of the Earth’s magnetism” (Murray, 1894). Murray finished his speech with proposals that the work should be undertaken by the RN and suggested a regime of two ships working over three summers and two winters. In his summary, the broad sweep of Antarctic science that can be addressed by such an expedition included:

> For the more definite determination of the distribution of land and water on our planet; for the better determination of the internal constitution and superficial form of the Earth; for a more complete knowledge of the laws which govern the motions of the atmosphere and hydrosphere; for more trustworthy indications as to the origin of terrestrial and marine plants and animals, all these observations are earnestly demanded by the science of our day.
>
> (Murray, 1894)

A turning point in the campaign for renewed Antarctic scientific exploring came at the International Geographic Congress of 1895. The congress was held in London and was well attended by geographers and scientists from around the globe. The congress passed a suite of twenty-one resolutions. The first two were procedural but the third set an International agenda.

> The exploration of the Antarctic Regions is the greatest piece of geographical exploration still to be undertaken. That, in view of the additions to knowledge in almost every branch of science which would result from such a scientific exploration, the Congress recommends that the scientific societies throughout the world should urge, in whatever way seems to them most effective, that this work should be undertaken before the close of the century.
>
> (Keltie & Mill, 1896, p. 780)

Upon becoming President of the RGS in 1893, Sir Clements Markham (1830-1916): “resolved that the Antarctic expedition should be dispatched during my presidency. I began work at once" (Markham & Holland, 1986, p. 5). Motivated by the positive response to the combined lobbying with Murray and Neumayer at the congress, Markham continued with the preparations already in train. Ultimately, the expedition became the BNAE and the expedition's aspirations were modeled on those initially proposed by Murray in his landmark speech to the RGS.

England was not the only country making preparations for Antarctic scientific exploration at the end of the nineteenth century. Germany had a history as the intellectual home of physical sciences, in particular terrestrial magnetism, since the days of polymath Alexander von Humboldt (1769-1859), mathematician, astronomer and physicist Carl Friedrich Gauss (1777-1855) and physicist Wilhelm Eduard Weber (1804-1891) (Gurney, 2000, p. 205). Gauss and Weber had established a magnetic observing network with forty-four observing stations, formalised in 1834 as the *Göttingen magnetische Verein*, also known as the Göttingen Magnetic Union (Cawood, 1979).

Planning for the First German Antarctic Expedition of 1901-04 had commenced in 1895 under the patronage of a commission for South Polar Research. The German Geographic Society convened the commission and the project proceeded under the directorship of Neumayer (Murphy 2002, p. 68). In an example of International scientific collaboration the ships *Gauss* and *Discovery* were dispatched to opposite sides of Antarctica in order to obtain complementary sets of data (Lüdecke, 2003). The *Discovery* was dispatched to the Ross Sea region, widely considered by Britain to be their exclusive field of exploration since its discovery by Ross. By mutual agreement the *Gauss* was sent to a sector south of the Indian Ocean, to maximise the exploratory and scientific value of the joint project and to test Neumayer's prediction of open sea at high latitudes in the sector. The abundance of expeditions between 1897 and 1916 is an indication of the success of the call for the renewal of south polar exploration and science that had been championed by Murray, Neumayer and Markham.

### 1.3 The potential for success of the *Discovery* expedition

The program of the BNAE was ambitious, but the prospects for success, both in the geographic and scientific objectives, were excellent. Admiral Sir R. Vesey Hamilton (1829-1912) said later in his review of Scott's narrative of the expedition "No polar expedition has ever been better equipped for exploration amidst ice" (Hamilton, 1906). During Markham's planning for the expedition between 1893 and 1901, he consulted with the experienced members of Arctic expeditions and scientists (Yelverton, 2000, pp. 32-38) and upon embarkation the ship was stocked with a comprehensive library of over twelve hundred volumes, of which nearly half were treatises on polar exploration (Fogg, 1992, p. 120). In addition, the *Antarctic Manual* published for the expedition contained numerous first hand accounts by polar explorers. This was intended as a guide for the officers, civilian scientists and crew (Murray and RGS, 1901). There was also a fine selection of popular literature (Baughman, 1999, p. 64).

A team of civilian scientists was recruited for research into the physical and natural sciences and ship's officers were trained as observers in meteorology, oceanography and magnetic science. The construction of the vessel was the single greatest expense of the BNAE. The *Discovery* was constructed as a floating laboratory for the investigation of terrestrial magnetism and oceanography. It was timber hulled in a time when steel hulled ships were more common and the vessel was equipped with features for ice work (Bernacchi, 1938, p. 11). The German expedition ship was also custom built and although not specifically fitted out for magnetic survey, the Scottish expedition, the *Scotia* under Dr William Speirs Bruce (1867-1921) and the Swedish, *Antarctic* under Dr. Otto Nordenskjöld (1869-1928) also committed to share scientific results. This coordinated International effort into terrestrial magnetism using purpose built vessels, the most modern instruments available and employing sophisticated coordinated observing regimes was *big* science of its time. Markham's plan to send out a new British expedition looked set for success.

## 1.4 The significance of this field of study

The *Discovery* returned to London in September of 1904. The publicity campaign included lectures by ship's officers and civilian scientists and an exhibition displaying sledging equipment, instruments, memorabilia, flags and pennants, photographs, watercolours and pencil drawings was mounted at the Bruton Galleries in London. ('Discovery' Antarctic Exhibition Illustrated Catalogue. n.d). There were banquets and official functions. King Edward VII entertained Captain Scott at Balmoral and heard his lecture accompanied by photos and watercolours (Yelverton, 2000, p. 328). Scott's official narrative, the *Voyage of the Discovery* was written and published within months of the return of the ship (Scott, 1905b). Hamilton reviewed the two-volume work in the *Geographical Journal* and confirmed what the frequent print runs and numerous editions indicated (Rosove, 2001, pp. 337-342), that narratives of polar travel telling of exploration and drama, as well as descriptions of life in the far south, were popular with the general public (Hamilton, 1906).

This research considers the success factors for Antarctic science in a structured manner and addresses a gap in an important topic in the history of science. Works focusing on the *Discovery* expedition make up a small proportion of polar literature and, of that, the scientific work is poorly represented. Terrestrial magnetism is an untapped field of research as a case study by which to judge success of scientific research on pioneer expeditions.

## 1.5 The research question

The elements of the *Discovery* expedition that made it ripe for abundant, quality outcomes in science and geography have been established above in Section 1.3 but there are a number of indications that opportunities may have been squandered, or that plans went awry. This research addresses a central question: Did the *Discovery* expedition achieve its potential in the research program into terrestrial magnetism and what were the drivers of scientific success that influenced that outcome? To answer that question it's necessary to consider the ways in which scientific outcomes can be measured in the most objective manner possible. Are these measurements or indicators of scientific success relevant to other disciplines, and of utility for assessment of the outcomes of other expeditions?

The *Discovery* expedition is of special interest because of its pathfinding role with respect to geographical, scientific and technical elements of Antarctic expedition organisation, especially for the Ross Sea sector. The geographical achievements now seem modest by comparison to the later overland journeys, but they significantly exceeded all previous efforts in south polar regions. The *Discovery* expeditioners made the first forays onto continental Antarctica and laid the foundation for explorations on later expeditions. Was the same true in relation to scientific programs? The key elements informing the research question are, for the expeditions of the Edwardian era, and for the *Discovery* expedition in particular:

- What were the indicators of scientific success in 1904?
- What were the drivers of scientific success at the time?
- How adequate were planning, recruitment, preparations and training?
- How was geomagnetic science performed?
- What were the *Discovery* expedition's magnetic science outcomes, how did they contribute to new knowledge in the discipline and how did each fare against the indicators of scientific success?
- Was the magnetic science on the expedition a scientific success and if so, what factors contributed to that success? If not, why?
- Did the *Discovery* magnetic science outcomes meet objectives and expectations, and could it have achieved more? If so, by what means?

The thesis question is examined through a framework of the success factors of scientific work on Antarctic expeditions of the era before World War I. Main elements of the framework are the historic and cultural contexts, patronage, finance and institutional support, leadership and governance, preparations, instructions and expectations, international collaboration, recruitment, training and knowledge acquisition, equipment and instruments, logistics, the work of the scientist, the social and intellectual climate on the expedition, luck and the post-expedition handling of data and collections in preparation for publication.

Recently published narratives concerning heroic era expeditions continue to debate Scott's leadership (Aldridge, 1999; Crane, 2005; Huntford, 1999; Yelverton, 2000). Although this research analyses and discusses the importance of planning, leadership, guidance and mentoring, the investigation is about the relationship between leadership and the quality of scientific output. Comparison of the characters of leaders of expeditions is irrelevant to this research, except where they intersect with the productivity or effectiveness of scientific inquiry.

This thesis investigates whether the efforts of magnetic work on the *Discovery* made a significant, genuine addition to knowledge and whether the proposed international collaboration bore fruit. A prospective outcome of this research is a guide for more objective assessments of the scientific programs on other expeditions.

## 1.6 Shape of the thesis

This research sits in the realm of history of science. The current perceptions of the scientific success of the expedition are consolidated into the next chapter that reviews conclusions found in current and significant literature related to the history of Antarctic science. The starting point for the body of research is consideration of the notions of scientific success in 1904. Indicators of scientific success are then identified, providing a set of standards against which the results of the *Discovery* can ultimately be measured. The central question of the research concerns the identification and assessment of the drivers of scientific success for expeditions of the era. These are also tentatively identified.

The third chapter outlines the methodology of the research and the theoretical basis that draws together the scientific and historic threads of the work. The thesis moves to the fourth chapter with examination of the cultural and historic contexts for the magnetic research on expeditions of the late Victorian and Edwardian eras. These determine the ways in which the intellectual traditions and the state of knowledge set the research agenda and shaped the preparations for the *Discovery*. The nature of the expedition preparations and their performance are then examined in chapter five to commence teasing out information that informed whether the scientific objectives were well served by pre expedition activities. Following the model established by Endersby (2008), the detail of the work of the scientists and observers on the expedition, firstly at sea, then in Antarctica, is investigated in detail with analysis of the magnetic observation program being the central focus through chapters five and six. Investigation of post expedition arrangements at the close of chapter six then reveals the manner in which the outputs (raw data and collections, publications, lectures etc.) were handled and whether the scientific outcomes such as new theory, paradigm shifts, altered intellectual traditions influenced the scientific community of the period.

The match between the outputs or outcomes, and the indicators of scientific success is reviewed in the first section of chapter seven to address the question about whether the expedition met its potential according to the expectations of its time. Finally, the second section of the chapter analyses of the relative impact of the drivers of success on the scientific outcomes as a test of the veracity of those drivers as a framework for objective analyses of other pioneer scientific exploring expeditions. Consideration of the validity of rankings of the drivers of success according to their relative influence on the expedition’s outcomes is a key element of chapter eight. The roles of managing institutions and key players are revisited and an overall assessment of whether the current perceptions of the *Discovery's* success are in agreement with the findings of this research are discussed. The thesis concludes with commentary on the enduring legacies of the *Discovery* expedition and consideration of the suitability of magnetic science as a case study to investigate the drivers of scientific success on pioneer polar expeditions.

# Chapter 2: Current perspectives of *Discovery* expedition science

An overview of the historiography of the *Discovery* and related Antarctic and scientific sources is provided in this chapter to relate current perceptions of *Discovery's* scientific achievements. One purpose of this research is to ultimately test the veracity of those perceptions, so the conclusions of authors and commentators about the overall success, the scientific success and in particular the success of the magnetic science program on *Discovery* form the core of this chapter.

The historiography of the *Discovery* expedition is generated from an almost finite set of materials. There is a suite of well-known repositories that includes the Scott Polar Research Institute (SPRI, Cambridge), the Royal Geographical Society (RGS, London), the Royal Society, (RS, London), the Alexander Turnbull Library, (Wellington, New Zealand), Canterbury Museum (Christchurch, New Zealand) and the State Library of New South Wales (Sydney) that collectively preserve the core of documents relevant to the *Discovery* and other Antarctic expeditions of the late Victorian and Edwardian eras. These institutions keep primary sources (journals and diaries, scientific reports, expedition narratives, official committee records, correspondence, autobiographies, photographs and ephemera) and secondary sources (biographies, histories, academic journals etc.). The body of publicly accessible source material is expanding only incrementally as descendants of early expeditioners donate materials, or auction them publicly allowing institutions to expand their archive collections. Only a handful of expeditioners lived to ripe ages and provided contemporary historians with oral histories. Clarence Hare (1880-1967) of the *Discovery* was living in Queensland and corresponding with the historian Les Quartermain (1895-1973) almost until his death (Hare, 1966) and Eric Webb (1889-1984), magnetician on Douglas Mawson's (1882-1958) *Aurora* expedition of (1911-1914) was interviewed for an oral history as late as 1975 (Webb, 1975).

The descriptions of the *Discovery* expedition developed from these resources are repetitive. Many Antarctic histories commence with chapters that are similar, using a chronological list of events as a format. These rarely add more than Scott's *Voyage of Discovery*, the original and official narrative, (Scott, 1905b). History of Antarctic scientific research fills only a minor niche in the abundant polar literature.

## 2.1 The modern sources of *Discovery* literature

Journals, personal narratives, correspondence, scientific reports and official records are the sources that constitute the core data for the substance of this research, but this chapter analyses the more recent, secondary sources in order to build a meta analysis of how the scientific achievements of the expedition are commonly perceived today. These secondary sources fall into categories according to subject matter, intended readership and style. Many of these secondary sources review the same materials but vary in their purpose, providing opinion or commentary on specific themes, events, topics or biographies. They range in accuracy from the scholarly (Yelverton, 2000, Barczewski, 2007) to biased (Aldridge, 1999, Jones, 2011) and what could be considered romanticised accounts (FitzSimons, 2011).

## 2.2 Antarctic scientific texts and reference sources

There are few books written specifically about Antarctic science, and most of those have a post International Geophysical Year (IGY, 1957-1958) and space science focus that describes current science rather than its history. In 1959 no one was better placed to write a scientific history of Antarctica than Frank Debenham (1883-1965). He was a veteran scientist of Scott's *Terra Nova* expedition (1910-1913) and the founding director of SPRI and had a lifelong interest in polar science. As a geologist he would have had a thorough understanding of terrestrial magnetic science. He describes the preparations for *Discovery's* magnetic observations at sea but neglects the onshore magnetic work entirely (Debenham, 1959, p. 74).

His account condenses the narrative of the *Discovery* expedition into a few pages and the only reference to expedition outcomes is inconclusive: “Once again, as in the time of Ross, the British had sent a well-found expedition and a fine leader and had reaped the benefit” (Debenham, 1959, pp. 74-78). His colleague Raymond Priestley (1886-1974) was another veteran of Scott’s *Terra Nova* expedition who held a long time connection with Antarctic science. *Antarctic Research* provides an introductory chapter to build historic context stating:

> The twentieth century opened with an international effort: Swedish, British, Scottish, German and French ventures, all with decided scientific aspect, being undertaken in the first three or four years. Only three-the Swedish, the Scottish and the French-concern us here, but these made major contributions.
>
> (Priestley, Adie and Robin, 1964, p. 4)

Inexplicably there is no mention of either *Discovery* or *Terra Nova* expeditions and by omission the authors imply that the *Discovery* did not make a major scientific contribution. Robin’s chapter “International Cooperation and Geophysics” only reflects on post-IGY science. (Robin, 1964, pp. 254-264)

Hatherton’s *Antarctica* is an edited collection of scholarly essays (Hatherton, 1965) most of which are solely concerned with the state of knowledge in the major scientific disciplines of Antarctic scientific enquiry at the time of publication. It is dense with scientific detail and has a focus on New Zealand’s Antarctic connections and scientific contributions, but is broad in its treatment of disciplines. The *Discovery* expedition is mentioned as being one of the expeditions during which the change from ship borne coastal mapping to continental (terrestrial) mapping was made (Miller, 1965, p. 88). Cullington’s chapter, *The Polar Magnetic Field and its Fluctuations* gives a brief history of magnetic science in Antarctica. The motivation for instructions to Wilkes, d’Urville and Ross to locate the South magnetic pole during their mid nineteenth century expeditions is clarified by the statement:

"Commerce across the seas was increasing and it was most important for the seafaring nations to have accurate magnetic charts showing the magnetic declination or variation of the compass" (Cullington, 1965, p. 463). The first Antarctic land based magnetic observing by Louis Bernacchi (1876-1942) and William Colbeck (1871-1930) on the *Southern Cross* expedition (1898-1900) is mentioned before the chapter moves directly to descriptions of the phenomenon of terrestrial magnetism and its theoretical background. No mention is made of the observations or scientific products of the *Discovery* expedition and the collaborative effort between the *Discovery*, *Gauss* and *Antarctic* expeditions is not acknowledged. Referring to observations made prior to the IGY, Cullington states: "As these measurements were not made simultaneously, and as they were confined to a limited sector of the Antarctic continent, it was not possible to derive synoptic patterns of the diurnal variation in the magnetic elements across the Antarctic continent" (Cullington, 1965, p. 468). The chapter provides a highly detailed synopsis of the ways in which features of terrestrial magnetic activity relate between Antarctic and lower latitude observations and is aimed at a scientifically literate audience. Although some conclusions are drawn from the results of Scott's *Terra Nova* and Mawson's *Aurora* expeditions, Bernacchi and the *Discovery* expedition are excluded from the discussion (p. 473).

*A Continent for Science* is another portmanteau for a wide coverage of post IGY scientific activities in Antarctica (Lewis, 1965). This monograph is written in an accessible style, and for a wider audience than Hatherton's edited collection. It has a focus on the U.S. contributions to science in Antarctica and is arranged by scientific discipline after the introductory historic review. The *Discovery* is dealt with in considerable depth compared to other books relating the history of Antarctic science (pp. 26-33) but unfortunately in his narrative of events Lewis confuses elements of the *Discovery* expedition with those of the *Terra Nova*. No conclusions are mentioned regarding the scientific outcomes of the

*Discovery* although the geographic exploits and "firsts" (balloon flight, furthest south) are mentioned. Lewis mentions the earth's magnetic field later in the book in relation to post IGY developments in cosmic ray observing and space weather (p. 203).

The preface to Harry King's *Antarctica* states the intention to introduce the reader to Antarctic science, and to provide basic facts concerning geography, natural history and exploration (King, 1969, p. i). The *Discovery* expedition is described as "The first extensive scientific expedition on the mainland of Antarctica" (p. 217). The geographic successes of the expedition follow and "useful work" was done in meteorology and the natural sciences. Again, the physical sciences and notably magnetic science are omitted. King's chapter on international collaboration covers the polar years of 1882-83 and 1932-33, then the IGY of 1957-58. The internationally collaborative scheme for magnetic observations between the *Discovery*, *Gauss* and *Antarctic* expeditions goes unacknowledged (p. 230-31). In common with other post-IGY books, terrestrial magnetism is dealt with under the general heading of atmospheric physics (pp. 86-99). A concise synopsis of the elements of terrestrial magnetism and (then) current observing methods is provided for the reader's education (pp. 88-90). King's monograph is brief but authoritative and is written for a general, not necessarily scientific literate readership.

John Béchervaise transports the reader to Antarctica and provides an imaginary tour of typical on base and scientific fieldwork activities (Béchervaise, 1978). Two centuries of the history of exploration and discovery are acquitted in one page (p. 93). Although a professional scientist and expedition leader himself, he condenses the history of science to such an extent that he skips from the *Southern Cross* directly to the *Terra Nova* expeditions without acknowledgement of the *Discovery*. Béchervaise deals with terrestrial magnetism in the category of *Particles from Space* (pp. 78-84). The operation of magnetic instruments and the relationships between terrestrial magnetism, lines of magnetic force, cosmic particles and auroras are described in sufficient detail for the non-scientist. This is a fine book but produced with a tight restriction on length and for a broad audience, but it does not expand general knowledge of the *Discovery* expedition.

*International Research in the Antarctic* is a thorough review of the state of Antarctic science at the time of its publication (Fifield, 1987). It dwells briefly on history and only mentions the names of expeditions and their leaders from the pre First World War era (pp. 24-25). The central concern of this book is post-IGY (1957-58) activities and specifically the role of the Scientific Committee on Antarctic Research (SCAR). Terrestrial magnetism is only mentioned in the context of solar wind and the earth's magnetosphere (p. 93) and there is no assessment of the scientific work of early expeditions. Walton's *Antarctic Science* (1987) also has a focus on the (post IGY) modern era of scientific investigation. It deals briefly with the historical background and devotes only a paragraph to the *Discovery* expedition. His general conclusion is that "…with six scientists on board and a strong scientific program, much was accomplished, and geographical exploration was not neglected" (Walton, 1987, p. 20). Erich von Drygalski's (1865-1949) *Gauss* also gets acknowledged as having made "…valuable magnetic and astronomical observations" (Walton, 1987, p. 18). The science of terrestrial magnetism is dealt with in depth under the topic heading of geophysics where he accurately states: "The history of the physical, as contrasted with the geographical exploration of Antarctica is not yet well known…" (Walton, 1987, p. 35). A short history of the quest for the south magnetic pole follows, with reference to the expeditions of Wilkes, d'Urville and Ross, before the discussion turns to the links between auroras and terrestrial magnetism. Scientific contributions of the *Discovery* to the field are omitted here also.

Fogg's *History of Antarctic Science* is an exception to the trend that Antarctic science books focus on post IGY activities (Fogg, 1992). It remains the most significant publication in the field and is the authoritative work on the history of Antarctic science. Terrestrial magnetism is dealt with in relation to the commencement of study of the upper atmosphere where the links between space weather and terrestrial magnetism are made explicit, before the work of the early expeditions is reviewed  (p. 315). The *Discovery* expedition is described and analysed under the appropriate banner of *Naval Tradition versus science* (p. 114). The preamble describes the lead-up to the expedition with a focus on the relationship between the RS and the RGS, the appointment of Scott and the resignation of Gregory (Fogg, 1992, pp. 114-120). Detail of the exploratory and scientific success are wrapped up with: "Vast collections of biological material were made by Wilson and Hodgson, the descriptions of them eventually filling five volumes published by the British Museum" (Fogg, 1992, p. 121). Fogg provides some additional commentary on early magnetic science, stating: "The magnetic observations made on the UK, German and Swedish expeditions were carried out according to internationally agreed protocol but the extensive data obtained do not call for any particular discussion here" (pp. 315-317).

In a more recent history of International scientific collaboration prompted by the jubilee of the Scientific Committee for Antarctic Research (SCAR) Walton & Clarkson give a brief overview of the discovery and early science of Antarctica. Roald Amundsen's (1872-1928) South Pole expedition is contrasted against those "With clear scientific objectives, like the first German Antarctic Expedition led by Erich von Drygalski: the Australian Antarctic Expedition led by Douglas Mawson and the British National Antarctic Expedition led by Robert Scott" (Walton & Clarkson, 2011, pp. 1-2). They believe that the scientific reports from these and other expeditions of the time (Belgian, French, Scottish, Japanese and Swedish) provided the foundation for present Antarctic science, although the scientific legacies varied widely.

Larson's *Empire of Ice* is a treatment of Antarctic science primarily confined in scope to the three British expeditions of Scott (*Discovery* and *Terra Nova*) and Shackleton (*Nimrod*) (Larson, 2011). Larson accurately states: "Books about the Heroic Age of Antarctic exploration could fill a library" (p. xi) and that "…most of these books-including some of the best-say little about science." The book is arranged by scientific discipline and the chapter *A Compass Pointing South* endeavours to cover the field with respect to terrestrial magnetism (pp. 27-60). A history of British maritime magnetic research, and the national and international context during the nineteenth century is laid out before the *Discovery* is dealt with in detail (pp. 27-49). A descriptive (rather than analytical) account of the activities of the *Discovery* follows (pp. 50-52) after which the focus shifts to Shackleton's *Nimrod*. The considerable terrestrial magnetic science work of Mawson's AAE and Scott's *Terra Nova* is not acknowledged. This monograph is the only recently published work on the history of Antarctic science with a strong coverage of the *Discovery* expedition. It commences to provide some depth about the operations of Bernacchi's magnetic observatory and the final published outputs (pp. 50-51). The uncritical, descriptive style makes the account accessible for non-scientists, but there is scope here for more critical analysis without loss of the flow of the narrative. Larson's focus on the first trek to the area of the south magnetic pole during Shackleton's *Nimrod* expedition betrays a lack of awareness of the potential of the *Discovery*'s at-sea observations and the possible scientific importance of the Antarctic winter station and sledge journey observations.

The expeditions operating in Antarctica during 1912 are the subject of a recent addition to polar literature, *1912: The Year the world discovered Antarctica* (Turney, 2012). It reviews the well-known polar bids of Scott and Amundsen, the scientific expedition of Mawson and the more obscure expeditions of Wilhelm Filchner (1877-1957) and Nobu Shirase (1861-1946). It has a strong focus on the scientific work of the expeditions and covers the work of *Discovery* briefly as historic context to the main body of the book. Turney mentions the tangible results of *Discovery* and states: “Even today, though, the expedition’s success is fiercely debated”, but aside from controversy over the expedition’s extended stay in Antarctica and the need for a government backed rescue mission, the reason for current debate is not explicit (Turney, 2012, p. 32).

In general, these monographs and collections dealing with Antarctic science and its history devote little space to the *Discovery* expedition’s contribution to terrestrial magnetism, and none extend to analysis of scientific outputs in other disciplines in any depth. With the exception of Larson’s *Empire of Ice,* all these science focused monographs make general statements about abundance of collections and valuable scientific contributions, but no criteria for the conclusions about scientific success are made explicit.

The student of Antarctic history is familiar with a handful of key reference sources. The premier resource is Headland’s *Chronology of Antarctic Exploration* that compiles all known details of commercial, exploratory and expedition voyages to Antarctica. Headland’s commentary on the outcomes of the *Discovery* expedition is terse, stating “comprehensive scientific programme conducted” (Headland, 2009, p. 24). There are three bibliographies of relevance. Rosove’s *Antarctica 1772-1999* deals with publication details of the literature related to expeditions in fine detail. In the case of the *Discovery* his focus is on Scott’s narrative and no evaluation or opinion of the expedition itself is offered (Rosove, 2001, p. 343-344). Spence’s *Antarctic miscellany* provides a detailed, but not comprehensive, listing of publications related to the key Antarctic expeditions including narratives, journal publications, charts and maps. References to *Discovery* are scattered throughout the work but there is no description, discussion or personal assessment of any of the expeditions mentioned (Spence, 1980). Conrad’s *Bibliography of Antarctic Exploration* (1999) provides some introductory discussion with each significant expedition. He provides a detailed synopsis of the evolution of the *Discovery* expedition (pp. 104-107) and specifically mentions the expedition objectives and the recruitment of the scientists and other key figures. Conrad's descriptions of the scientific activities and sledge journeys are of interest but he does not provide analysis or opinion of the outcomes of either the scientific or exploratory program.

Riffenburgh's *Encyclopedia of the Antarctic* is a genuine reference tool. *Discovery* expedition science is cited in a positive light: "The British National Antarctic Expedition was one of the most important expeditions of the Heroic Age, and its scientific accomplishments indicate that this voyage was a first rate effort" (Riffenburgh, 2007, p. 201). The connection between RS patronage and Antarctic science of both of Scott's expeditions is found later in the work: "The scientific output was outstanding, and Scott's second expedition received advice and financial support from the Society" (p. 820).

Two large illustrated encyclopedic volumes are in common circulation. Both attempt a wide coverage of Antarctic history and exploration, some current science, geopolitics, wildlife and landscapes. The Reader's Digest *Antarctica* compilation includes a section devoted to the quest to locate the south magnetic pole where the voyages of d'Urville, Wilkes and Ross are described (Reader's Digest, 1990, pp. 102-103). Some theoretical background regarding the sources of terrestrial magnetism and the influence of space weather provides context but no reference is made to either the *Gauss* or *Discovery* expeditions here. In the expedition history section the key exploratory achievements during the *Discovery* expedition are a focus but there is no mention of scientific objectives or outcomes aside from the fact that Edward Wilson (1872-1912) collected numerous zoological specimens. McGonigal and Woodworth's *Complete Story of Antarctica* is a similarly informative and well-illustrated volume. It also provides a short history of the *Discovery* expedition and comments superficially on its scientific work: "Recent analysis has shown that Scott …achieved much for Antarctic science, and documented some of the definitive events of the Heroic Age of Antarctic exploration” (McGonigal & Woodworth, 2001, p. 426).

## 2.3 Biographies

There are numerous biographies of Antarctic expedition leaders, especially Scott, Shackleton, Amundsen and Mawson. Murray cites estimates of more than 625 biographies of Scott alone. (Murray, 2006, p. 1). There is also a growing trend to publish biographies of less prominent Antarctic expedition figures like Bernacchi, (Crawford, 1988) Apsley Cherry-Garrard (1886-1959), (Wheeler, 2002) Tom Crean (1877-1938), (Smith, 2000) Tannatt Edgeworth David (1858-1934), (Branagan, 2005) Reginald Koettlitz (1860-1916), (Jones, 2011), Frank Wild (1873-1939), (Butler, 2011) and Wilson (Williams, 2008). These biographies vary in quality but many are thoroughly researched and, although the scientific work of expeditions is generally not a central topic, observations and opinions of the authors scattered through such works can be instructive to the researcher of the history of magnetic science. Biographies of Scott are, understandably, strongly focused on the *Terra Nova* expedition. Laurence M Gould wrote:

> The brilliance and tragedy of the second Scott, or *Terra Nova*, expedition (1910-1913), of which Wilson was a member and on which he, along with Scott and others, lost his life, has understandably obscured the significance of the *Discovery* expedition. Except for the experience and the achievements of the first expedition, however, the second one could hardly have been made.
>
> (Gould, 1967)

The developments that culminated in the struggle, then death of Scott and his companions a century ago, after their attainment of the South Geographic Pole make up a master narrative that is rarely matched. Most biographies follow a chronological sequence and the *Discovery* expedition is often presented as a vignette that demonstrates Scott’s initial personal growth from RN career officer to heroic explorer. In response to attacks on Scott’s image (such as the representation of Scott as incompetent in Huntford, 1999) his image has been re-crafted as a scientist who also did some polar exploration, rather than an explorer that engaged with science as a means to legitimise expeditions and maximise funding opportunities. Biographies reveal thoughts of historians, scholars and journalists regarding the *Discovery* scientific work. Some offer opinions regarding the success of the expedition, both in terms of exploration, and in terms of scientific outcomes. Others are silent on the matter of science. For those authors, science might be unimportant, irrelevant or off-topic. Alternatively, it may be too challenging for investigation and development of informed opinions or merely of little interest to the wider readership.

During research for his biography of Scott, Pound worked with the approval of expedition descendants and had access to primary documents previously kept private. He brought a new light on the character of Scott, summing up the achievements of the *Discovery* thus: "The world was told through the news agencies that Scott had returned to England with more varied and valuable scientific information than had ever before been collected in the Antarctic regions" (Pound, 1966, p. 115). This glowing report is at odds with his own preceding comments about the competence of Scott's naval staff to make scientific observations: "His reliance on the ability of his naval colleagues, in particular, to make scientific observations and deductions on the basis of brief training given them before leaving England was in some instances misplaced" (p. 40). Pound also hints at deficiencies in the dredging and trawling outcomes that were a consequence of limited opportunities to trial the gear (p. 46). Contrary to the assertion by Finkel (1976, p. 57) that the second season (1903) added little to the observations from the first (1902), Pound states "he [Scott] assured the learned societies that much of the best work was done during the expedition's controversial second year in the Antarctic" (Pound, 1966, p. 116).

Crane's biography of Scott is one of the few that addresses the scientific successes of the *Discovery*:

> On top of *Discovery's* geographical, surveying and geological results, Wilson's work on the fauna of the area and Bernacchi's own observations –magnetic records for something like six hundred days collected under the most appalling conditions-were enough alone to ensure the scientific value of the expedition.
>
> (Crane, 2005, pp. 307-308)

Crane also suggests: "The massive volumes of results and observations that came out … are the unarguable legacy of *Discovery's* scientific work" (p. 308).

Huxley's biography of Scott covers the *Discovery* expedition at length. A positive view of the scientific results is conveyed in her description of the expedition's return to England: "Word was beginning to get round that this had been outstanding, both in geography and in science" (Huxley, 1977, p. 168). She cites Markham's speech at the East India Docks welcome home luncheon event of 16 September 1904: "Never has any polar expedition returned with so great a harvest of scientific results" (p. 172). This statement is the likely root of the oft-repeated view that the abundance of the specimens and data indicated success of the expedition. Huxley follows with a list of the achievements including acknowledgement of the two years of continuous meteorological and magnetic observations (p. 173).

In Huntford's *Last Place on Earth* magnetic science at sea and ashore on the *Discovery* expedition is not acknowledged and there are no assessments of scientific outcomes (Huntford, 1999). Acrimony between Scott and the RS over the first meteorology report is highlighted (p. 230) and comparisons between the lengths of new coastline charted by Bruce's *Scotia*, Jean-Baptiste Charcot's (1867-1936) *Français* and the *Discovery* cast the achievements of the latter in a poor light (p. 180). He states "Nordenskjöld was a model scientific leader; so was Drygalski" and his failure to comment here on Scott's leadership might imply a view that Scott was deficient in leadership skill (p. 180). Huntford's earlier biography of Shackleton has one oblique reference to magnetic science on the *Discovery*. He reiterates a quote by Shackleton from the *Illustrated London News* supplement of 27 June 1903, after he was repatriated: "For the furtherance of…magnetic research the Government had given £45,000 and…we have been successful in carrying out what was intended" (Huntford, 1985, p. 122). Shackleton was no physicist and demonstrated little interest in science, so it's unlikely he would have known whether the magnetic results were of value.

Balance against the negative portrayal of Scott by Huntford is achieved in Fiennes' subsequent detailed biography. Magnetic science at sea on *Discovery* is acknowledged with mention of the investigation of "magnetospheric anomalies" at 65° S during the outbound voyage (Fiennes, 2003, p. 48). The southeastern ("Barrier") sledge journey by Charles Royds (1876-1931) and Bernacchi of late 1903 is described as yielding "key data about the region's magnetic characteristics" (p. 128). Fiennes summary of the scientific achievements are genrally positive.

> Although, as with most successful scientific projects, the findings of the *Discovery* expedition would take many years of specialist work to analyze, it was already clear that Scott's scientists had been hugely successful, especially during the second season…Scott's *Discovery* achievements far outweigh those of contemporary scientific leaders Nordenskjöld in 1901 and Drygalski in 1902.
>
> (Fiennes, 2003, p. 128)

Fiennes subsequent book, *Race to the Pole,* is part biography and part history, and reiterates much of the same content (Fiennes, 2004) and presents an even more positive view of the scientific work. Bernacchi's synchronised magnetic observations (p. 71) and the Barrier sledge journey yielded "key data about the region's magnetic characteristics" and "extensive new data had been collated" (Fiennes, 2004, p. 118). In terms of outcomes from the cooperative relationship between the German and English expeditions, Fiennes states:

> Louis Bernacchi kept magnetic records, often synchronized with those of Drygalski's German team. Which, when added to the observations of Armitage and Mulock, located the precise position of the south magnetic pole as accurately as if they had reached it. Their results, together with those of Drygalski, enabled the construction of a magnetic map of the Southern Hemisphere, which had been the Anglo-German aim and which proved key to the navigation of the southern trade routes until the evolution of satellite navigation.
>
> (Fiennes, 2004, p.135)

Barczewski's book describes the waxing and waning of the reputations of Scott and Shackleton in recent years is mostly concerned with tracking and interpreting opinions (Barczewski, 2007). Her monograph opens with examples of different portrayals of Scott and Shackleton from the body of literature and her assessment of the *Discovery's* achievements is balanced. "The *Discovery* returned to England in 1904 to a professional and public reception in keeping with its accomplishments, which were impressive from a scientific point of view, but not particularly glamorous" (Barczewski, 2007, p. 4). She then states: "The British public quickly came to recognise that the expedition had added enormous amounts not only to human knowledge of Antarctica, but to scientific knowledge more generally" (p. 43). More specifically: " Tremendous amounts of new biological, meteorological and geographic data were obtained. Precise observations allowed the creation of a magnetic map of the hemisphere, a great boon to marine navigation in the days prior to satellite mapping" (p. 43). In footnotes she states: "The importance of the *Discovery* expedition's scientific achievements remains in dispute, but by any standard it added immensely to contemporary knowledge of Antarctica." Then, without explanation of her yardsticks for success, she writes: "Certainly the *Discovery* expedition accomplished far more than the German, Swedish and Scottish expeditions that explored Antarctica at the same time" (footnote 98, p. 323).

Koettlitz was the senior surgeon to the *Discovery* expedition and his first biography has only recently been published (Jones, 2011). It focuses on the scientific contributions of

Koettlitz and there are no general conclusions regarding the achievements of the expedition. There are implications that the scientific work was not taken seriously by Scott, and was ineffective. Jones quotes correspondence from Koettlitz to Fritjof Nansen (1861-1930) near the end of the expedition, at sea on 29 August 1904:

> These naval and other officers look upon everything that happens and that they do as a 'bit of fun', as sport, and they do it in a sporting style. There is no backbone in it, and much of it is carelessly done. There is also too much of the official tradition in it, and too much 'red tape.' Never the less work has been done.
>
> (Jones, 2011, p. 178)

Crawford's biography and collection of her grandfather Bernacchi's edited diaries from Carsten Borchgrevink's (1864-1934) *Southern Cross* expedition, touches only briefly on the *Discovery*. Scientific work is mentioned in the context of visits to the Cape Adare site by the *Discovery*, at which time Bernacchi repeated magnetic observations at the same location he used during the *Southern Cross* expedition (Crawford, 1998, p. 219-221). Bernacchi is often cited in the literature related to the *Discovery* expedition, not because of interest in his terrestrial magnetism studies, but because he was a prolific diarist and post expedition author. Skelton has edited a similar work based on the diaries and photographs by her grandfather, Reginald Skelton (1872-1956), first engineer of the *Discovery*. In the preface she states: "*Discovery* can truly be said to have laid the foundations of scientific research in Antarctica" (Skelton, 2004, p. 5). Williams' recent biography of Wilson, second surgeon to the expedition, repeats the message about quantity of outputs. "The *Discovery* expedition could claim success in terms of magnetic research, geology, biology, and meteorology; the scientists had gathered a large body of material about the Antarctic" (Williams, 2008, p. 177). This biography shows a strong bias towards geographical achievements and neglect of scientific achievements. It highlights the value of Wilson's artworks as a record of those achievements.

In summary, the biographies add little critical analysis of scientific success on *Discovery* and the theme that abundance of data and material in natural science collections indicates success is perpetuated. In the rare cases where opinions are ventured about scientific success, the criteria for making the judgement are not explicit.

## 2.4 Histories

Finkel's obscure but engaging book remains significant as one of the earliest pieces to directly criticise Scott's decision making. Unfortunately the author does not cite the sources and the book has no index, so its value to scholarship is limited, but he had an awareness of the potential unpopularity of his opinions:

> There have been almost as many books written about Scott as there have been about James Cook, and for many years it was near heresy to question Scott or his methods. Any mistakes made were glossed over by the tragedy of the deaths of his party.
>
> (Finkel, 1976, p. 153)

The book provides a descriptive narrative of events on the *Discovery* and *Terra Nova* expeditions, including appraisal of Scott's achievements and failings. He comments on the scientific background to the *Discovery*:

> Most expeditions during the Heroic Age included a few scientists, but the great driving force of the day was geographical discovery. Much of the money they needed was raised by public subscription and the ordinary man was not stirred by the importance of magnetic research, or the nesting habits of penguins.
>
> (Finkel, 1976, p. 42)

This history is well balanced and with respect to the *Discovery* expedition, after listing a number of Scott's progressive methods and geographical achievements Finkel writes:

> Scott made a mistake by allowing the ship to be frozen in. He did not have to do it and no other explorer of the Heroic Age did so deliberately, although it sometimes

> happened by accident. The second, involuntary season added little to the brilliant first year of the expedition.
>
> (Finkel, 1976, p. 57)

Finkel's closing assessment is: "The *Discovery* Expedition was a success. Scott made mistakes, but he appeared to learn from them and on his first expedition he did not make the same mistake twice" (Finkel, 1976, pp. 153-154).

Martin utilised his access (as librarian) to the resources of the State Library of New South Wales to produce an engaging illustrated history of Antarctica based on, and using, extensive quotes from primary sources. The history spans the first speculations about the existence of the continent through to the IGY. Various events from the *Discovery* expedition are related through nine pages of vignettes from journals (Martin, 1996, pp. 115-124). In summarising the *Discovery* achievements, he states: "The scientific work of this expedition is often overlooked in the aura of the romantic wonder which surrounds Scott and his expeditioners" and follows with: "Masses of data in meteorology, magnetism, geology and biology were collected" and then addresses magnetic science directly, but superficially stating: "The detailed magnetic records established a synchronicity with magnetism in the northern polar regions" (Martin, 1996, p. 124).

Scholes' saga of Australian exploration of Antarctica includes material on the *Discovery* expedition due to the contribution of Bernacchi who grew up in Australia. The history lends a great deal from Bernacchi's own narrative *Saga of the Discovery* (Bernacchi, 1938). Scholes provides a positive view of the outcomes of the expedition: "When the second summer was ended, the expedition knew much more about this new world. The men were rich with the treasure of knowledge, of geography and other scientific matters" (Scholes, 1953, p. 85). Summing up, he concludes: "Scott's first expedition was a tremendous scientific success" (Scholes, 1953, p. 89).

Nichol's history from the same period mentions Scott's sympathy with science: "…a man not only born to command, but in full sympathy with every branch of scientific work." Nichol follows with the comment that the main objective on the *Discovery* expedition was "to conduct a magnetic survey" but he does not mention the results of the magnetic science, or those of any other discipline (Nichol, 1948, pp. 54-55).

Kirwan was Secretary of the RGS from 1945 to 1975 (M. W. R., 1999) placing him well to access primary resources for the section on the *Discovery* history in his monograph (Kirwan, 1962, pp. 253-270). He understandably focuses on the geographical achievements of the *Discovery* but turning to science he wrote:

> During both seasons a massive accumulation of scientific observations was made. Their subsequent publication in a series of magnificent volumes remains to this day a tribute to the great stride forward made by the expedition in the development of Antarctic science.
>
> (Kirwan, 1962, p. 267)

Another author that makes statements of success based on quantity of results is Church who, when reviewing the centenary of the connections of Dunedin and Port Chalmers with Antarctic expeditions, comments on the results of the *Discovery* expedition: "so much information had been collected that evaluation and publication were far from complete when Scott made his second expedition in 1910" (Church, 1997, p. 17).

Aldridge's *Rescue of Captain Scott* does not paint a positive view of Scott's leadership. He mysteriously reinterprets Kirwan's history: "Like Hugh Mill, he concluded that the expedition of 1901-1904 was not a great scientific success: he regarded it simply as a dramatic adventure" (Aldridge, 1999, p. 171). His discussion of the *Discovery* opens with exploratory successes before shifting the focus to the science disciplines. Magnetic studies are covered haphazardly with a short introductory history of magnetic science but Aldridge is ignorant of the instruments used and fails to describe the nature of work undertaken by

Bernacchi. In spite of the chapter title, (‘*Discovery’s’ Expedition Achievements*) none of the achievements in the magnetic science discipline are mentioned (Aldridge, 1999, pp. 57-64).

Spufford’s *I may be some time* is a cultural history of our obsession with polar history and figures. It is not a history of Antarctic exploration, but makes comments on the style of Antarctic histories. He is an acute observer of motivations and cultural contexts but does not express opinion about the outputs of the *Discovery* expedition (Spufford, 1996). Preston investigates the “mystique and enduring power of Scott’s last expedition” and describes the events of the *Discovery* expedition as a prelude to deeper analysis of the later *Terra Nova* expedition and its symbolism (Preston, 1997, p. 7). Like many commentators, she describes Bernacchi’s magnetic observations as “valuable” (p. 76) and that “Important magnetic, meteorological, geographical and zoological research had also been completed…” (p. 82). Describing *Discovery’s* reception on its return in 1904 as muted, she reiterates Markham’s comments about the great harvest of scientific results and notes Scott was gratified by the “growing climate of approval” to the achievements of the expedition that followed what she called pre-expedition uncertainty by the scientific establishment (Preston, 1997, p. 101). Jones’ *Last Great Quest* is a similar book in architecture and content. Quotes from news items around the September 1904 return of the expedition are used to demonstrate the prevailing mood that the expedition was successful in a general sense, as well as scientifically (Jones, 2003, p. 68). Referring directly to science, the author mentions that the expedition “…gathered detailed observations of natural phenomena and vast collections of samples.” These positive messages are tempered with a cautionary note:

> The claim that the NAE returned with ‘the richest results, geographical and scientific ever brought from high southern latitudes’, should certainly be treated with caution, as the expeditions of William Bruce, Jean Charcot, Otto Nordenskjöld and Erich von Drygalski, also produced a wealth of information about Antarctica.
>
> (Jones, 2003, p. 70)

Rosove's *Let Heroes Speak* is contains accounts from expedition narratives spanning from Cook's 1772 (*Resolution* and *Adventure*) to Shackleton's 1922 (*Quest*) expeditions. The section on *Discovery* opens with a statement of achievements: "The significance of this voyage's accomplishments cannot be overestimated. Well organised, the program was a logical and thorough extension of Ross's geographic discoveries and research in all relevant branches of science" (Rosove, 2002, p. 83). Magnetic science at sea on the outbound leg is acknowledged: "Scott made a southward diversion to the sea ice to obtain magnetic readings." (p. 85) and on the homeward leg: "Magnetic surveys were made in the Pacific as far as 56° to 60° S." (p. 105).

Griffiths gives a rich social history of Antarctic expeditions in his collection of essays, *Slicing the Silence* (Griffiths, 2007). Early polar magnetic science is acknowledged without direct reference to the *Discovery*, but he provides deeper context of magnetic and meteorological field research:

> The tending and reading of the essential instruments was, in Antarctica, heroic and fraught with danger…Both sciences required long, laborious runs of data so that variations over space and time might be mapped. Both were inspired by global Humboldtian science, by the desire to embrace the cosmos with measure and pattern. But they also had quite practical purposes: meteorology was a vital key to survival, and magnetism had long been a tool of empire because understanding terrestrial magnetism and its declination and dips was crucial to better use of compasses and navigational safety.
>
> (Griffiths, 2007, p. 45)

Wilson timed the release of his compilation of photographs taken by Scott on his final journey to match the centenary of that event. There is a comprehensive preamble to the story of the *Terra Nova* expedition in which Wilson discusses the overlap between geographical exploration, adventure and scientific inquiry in the polar context. Referring to the *Discovery* expedition he states: "Once the expedition returned, the geographic and scientific findings, while imperfect, were of undoubted value and the scientific cooperation was deemed a great success" (Wilson, 2011, p. 26). Hooper's *Longest Winter* is an account of the eastern scientific party (later referred to as the "Northern Party") of Scott's *Terra Nova* expedition. It brings out the contrast between preparation and recruitment for the scientific programs on Scott's two expeditions: "On Scott's first expedition, some scientists had been selected on a fairly haphazard basis, and in certain cases results had been heavily criticised. This time men had been sought out with professional competence" (Hooper, 2010, p. 203). The reference to "heavy criticism" was written abut the struggle by Scott to maintain credibility with, and the support of the RS during preparations for the *Terra Nova*, at which time he was also in conflict with the Society over errors published in the first meteorology report of the *Discovery* (Meredith Hooper personal communication, 14 September 2011).

Three recent publications focus on the history of the compass, terrestrial magnetic science and the quest to locate the south magnetic pole. Gurney's *Compass* (2004) focuses on the technical development of compasses, especially those intended for maritime navigation. Although theories of terrestrial magnetism and its connection with navigation are mentioned throughout the book, there is silence on the Antarctic expeditions at the turn of the twentieth century. Turner's *North Pole, South Pole* (2010) describes the quest to solve the riddles of terrestrial magnetism and paleomagnetism. This thorough work covers the long history of magnetic observing and theorizing, and connects those activities with geology and plate tectonics. The expeditions of Ross, d'Urville and Wilkes are not mentioned, nor are those of Scott, Drygalski or Mawson. These expeditions had magnetic science as core research or investigation but they are outside the scope of content. Mawer's *South by Northwest* (2006) devotes a chapter to the *Southern Cross*, *Gauss* and *Discovery* expeditions. As with Turner and Gurney, significant background research underpins the monograph and the author shows an understanding of the science. Preparations for the expeditions, their expectations and their operations are described in detail. While Mawer does not dwell on the scientific activities of Bernacchi on the *Discovery*, he notes that Scott provides only nominal coverage of it in his *Voyage of 'Discovery'* narrative, (Scott, 1905b, pp. 280-282). Although Mawer engages with the connection between the *Discovery* expedition and magnetic science, he fails to provide analysis or opinion regarding the value of the scientific results.

Two monographs relate the history of the *Discovery*, from its construction in 1900-01 until the end of its working life. The first of these is Bernacchi's *Saga of the Discovery* that was published long after many of Bernacchi's shipmates had passed away (Bernacchi, 1938). It provides a sentimental narrative of the ship's history and his conclusion about the value of the Antarctic science of the expedition is generally sanguine: "Never had a polar expedition come home with so great a harvest of original research work, nor have such original results been surpassed by subsequent polar expeditions…" (Bernacchi, 1938, p. 113). His following statements are less committed in regards to quality or meaning of outcome.

> The extensive physical work, part of an international programme, for which I was responsible, was one of the principal objects of the expedition. It was completed. In due time the scientific work was reduced, discussed and published in many large volumes by the Royal Society.
>
> (Bernacchi, 1938, p. 114)

The second work is a more recent and more scholarly account by Savours, a long serving member of SPRI. It provides a more scholarly version of the ship's construction and operations during active service. Savours' only personal assessment of the results of the expedition is: "*Discovery* had completed a rewarding first voyage, and the expedition she carried made a splendid contribution to Antarctic geography and science" (Savours, 2001, p. 70). She quotes extensively from Bernacchi's account without adding further analysis for the student of the history of science, in spite of her unrivalled access to primary resources. Tarver's *S.S. Terra Nova* is written in similar style. The *Terra Nova* was one of the two ships involved in the *Discovery* relief expedition of 1904. Tarver comments on *Discovery's* outcomes:

> On the return of *Discovery* to Britain, the British National Antarctic Expedition was acclaimed an outstanding success both scientifically and territorially. Much new material was brought back for evaluation and important sledge journeys inland had been made including a journey 'farthest south'- further than man had ever been before.
>
> (Tarver, 2006, p. 49)

Holland's *Antarctic Obsession* is an edited collection of Markham's illuminating personal records related to the *Discovery* expedition. Holland's introduction discusses the products of the expedition:

> Its main results were geographical, geological and biological discoveries in the Victoria Land region, and Markham was later to claim that 'never has any polar expedition returned with so great a harvest of results!' It was, nevertheless, conducted with a minimal scientific staff and its scientific results were modest beside those of some smaller and more efficient expeditions of the same period.
>
> (Markham & Holland, 1986, p. xv)

Holland's perceptive comments cast doubt on the dominant paradigm that an abundance of data and specimens implies success.

Baughman's *Pilgrims on the Ice* is one of a pair of complete histories of the *Discovery* expedition. The monograph is a concise chronological description with analysis of the social landscape and with some insights into the motivations of individuals. The scientific activities are not central to the narrative but some elements of interest are covered. Bernacchi's scientific contributions in Christchurch, (Baughman, 1999, p. 84) at Capes Adare (p. 97) and Crozier, (p. 102) and his regime of observations at Winter Quarters (p. 152) are mentioned. Baughman also notes that in the second winter "Scientists in each department had both improved the methods of their research and added substantially more to the body of scientific data than could have been imagined at the close of the 1902-03 summer"

(Baughman, 1999, pp. 220-221). Baughman summarises: "The essential question about the expedition was settled before the first sail was set: adventure triumphed over science…" (p. 261) then continues with some assessment of the outcomes. In respect of scientific leadership he states that: "Given Markham's qualifications for the position, Scott probably was a better commander than the expedition deserved, for his ability as a scientific leader emerged as one of his strongest qualities" (p. 261). He sums up: "Mindful that the expedition was founded on the failed models of nineteenth century British Arctic exploration, the accomplishments merit great praise" (p. 262) and "the men of the *Discovery* accomplished a great deal in terms of science and adventure" (p. 263).

Yelverton's *Antarctica Unveiled* is the second in the pair and is the most significant single publication on the *Discovery* expedition since Scott's own narrative. It provides a scholarly analysis of all elements of the expedition and (like Baughman) ties together information from primary sources. Yelverton is the only author to provide a truly meticulous analysis that follows the stepwise processes building towards his conclusions. For example, he describes the magnetic observing huts and instruments used by Bernacchi and the regime of term day and term hour observations (pp. 146-147). Although Yelverton does not make any strong closing statements in regards to the products of scientific work on *Discovery*, he states that it was the forerunner of later Antarctic scientific expedition work. In respect of the magnetic observations related to accurate location of the magnetic pole, only one element of the magnetic program, Yelverton states (referring to Scott):

> His own and Bernacchi's and Mulock's observations on their journeys would locate the magnetic pole almost as well as if they had actually been to it, certainly well enough to build the magnetic map of the Southern Hemisphere that had been one of the prime aims of the European assault, of which his expedition had been part. Their endeavours had surely reaped a rich harvest.
>
> (Yelverton, 2000, p. 311)

The outcomes of the magnetic research are not covered in Yelverton's analysis or conclusions.

## 2.5 Scholarly articles and proceedings of conferences and symposia

To mark the centenary of the return of the *Discovery*, a symposium was held at the Southampton Oceanography Centre, the intellectual home of the *Discovery* expedition biologist, Thomas Vere Hodgson (1864-1926). It brought together scholars interested in polar sciences and the scientific history of the various voyages of the ship. The papers are collected in one volume of *Archives of Natural History* (Nelson, 2005, pp. 127-394). Disciplines covered include glaciology, meteorology, hydrology, oceanography, plate tectonics and geomagnetism and synoptic papers by Fogg and Walton bookend the collection (Fogg, 2005, pp. 129-143; Walton, 2005, pp. 394-401). The introductory note by the editor sets the scene for the collection: "In 1904 the steam yacht *Discovery* (I) returned to the United Kingdom after a highly successful voyage of scientific exploration" (Nelson, 2005, p. 128). The keynote address by the eminent historian of Antarctic science, G. E. (Tony) Fogg also cites the scientific achievements of the expedition: "The British National Antarctic Expedition (1901-1904) on the *Discovery* (I) became one of the foremost in scientific output among the several dispatched from Europe to the Antarctic about this time" (Fogg, 2005, pp. 129-143). This sentiment echoes his earlier paper on the RS and the Antarctic, where he states "Scientifically, as well as geographically, the expedition, which returned to England in September 1904, was a success" (Fogg, 2000, p. 90).

Savours' history of RN and private vessels named *Discovery* focuses on the achievements of Cook on his third (*Discovery* and *Resolution*, 1776-1780) expedition and here she does not venture an opinion on the scientific or exploratory achievements of the BNAE (Savours, 2005, pp. 144-160). On a related theme, the paper by Rice illuminates incidents of serious conflict between scientific staff and ships officers on voyages of exploration and his omission of Scott or the *Discovery* in this context implies that there were no notable conflicts. (Rice, 2005, pp. 177-191). Headland's synoptic paper covering the phases of history of Arctic and Antarctic exploration and science mentions that the *Discovery* expedition was "…successful in most of its objectives…" and the paradigm that the number of publications indicates scientific success is affirmed by: "Ten scientific reports, from 1907 to 1911, resulted…" (Headland, 2005, p. 207-220). Rainbow quantifies and analyses the contribution of the natural science collectors on *Discovery's* many scientific voyages that spanned between 1901 and 1931 (Bryan, 2011, p. 343). The significance of the collection from the BNAE as a reference collection in the BMNH, as well as numerous type specimens (examples of newly discovered species on which their taxonomic status was established), attest to the zeal of Hodgson, the biologist who compensated for the "limited oceanographic work" by working throughout the polar winters, dredging and netting through holes in the sea ice off Hut Point (Rainbow, 2005, pp. 221-230).

McConnell's *Surveying terrestrial magnetism in time and space* is directly relevant to this research (McConnell, 2005, pp. 346-360). McConnell is a pre-eminent historian of polar magnetic research and the evolution of related instruments. After tracking the intellectual development of terrestrial magnetic theory from the twelfth century to the First World War, she describes important voyages of exploration and scientific enquiry, and covers the development of some of the instruments used by the physicists Bernacchi of *Discovery* and Freidrich Bidlingmaier (1875-1914) of *Gauss*. It is here that the first clues about possible shortcomings of magnetic science on the *Discovery* emerge in the accessible literature. Referring to comments about the Lloyd-Creak dip circle in Louis Agricola Bauer's (1865-1932) report from the Carnegie Institution's Department of Terrestrial Magnetism (Bauer, Peters, Fleming, and Ault, 1917, p. 19), McConnell states: "Because of the defects in the instruments issued to the *Discovery*, however, the intensity observations made at sea were not published" (McConnell, 2005, p. 355). The contribution by the *Discovery* towards accurate location of the south magnetic pole, and the two years of almost continuous magnetic observations by Bernacchi at Hut Point, are not specifically mentioned within her review of efforts to locate and arrive at the magnetic pole (pp. 356-357).

Walton's closing paper of the symposium collection confirms the contribution of the *Discovery* expedition to the shift from exploration to science as the prime motivation for Antarctic expeditions of the twentieth century (Walton, 2005, pp. 394-401). Amongst a generally sanguine synopsis of these contributions he refers specifically to terrestrial magnetic research stating: "Whilst Scott's first expedition did not make any major progress with magnetism the equipment limitations meant that even during later attempts on Shackleton's expedition … they would be uncertain they had arrived at its exact location" (Walton, 2005, p. 397).

Lüdecke is a historian that specialises in the scientific elements of Drygalski's *Gauss* expedition and early polar international collaborations. Like McConnell, she adds doubt to the value of outcomes from the *Discovery*. In her article on the scientific collaboration between expeditions of 1901-04 she states: "Data of the magnetic field of the Earth measured by *Discovery* and *Gauss* improved the charts of the southern seas, but there had not been enough data to cover large areas" (Lüdecke, 2003). More recently she has reiterated her view of outcomes of collaboration between *Discovery* and *Gauss*: "Data on the magnetic field of the earth, measured by the British *Discovery* and the German *Gauss*, did not cover large areas, but improved the nautical charts of the southern seas." In respect to the Antarctic base station observations, Lüdecke describes the arrangement between the British and Germans for term day and term hour observations but does not ciomment on outputs (Lüdecke, 2010, pp. 128-132).

The selection of academic papers and reports from symposia indicates that magnetic research on *Discovery* is generally dealt with in those forums in a superficial manner, and the measure of worth of outcomes is most often the number of official scientific reports published after wrap up of the expedition. There is little genuine analysis of the research into terrestrial magnetism.

## 2.6 Other sources

There are few theses based on research into the history of Antarctic science, and none that are specifically focused on either science of the *Discovery* expedition, or magnetic science in the Edwardian era. Hunt's M. Phil. thesis is concerned with the development of magnetic instruments during the nineteenth century, and is focused on British Arctic exploration (Hunt, 1995). Murray's doctoral thesis investigates the enduring power of the story of Scott's fatal polar trek and suggests that, like the abandoned *Terra Nova* polar hut on Ross Island, the story that gives the hut meaning also needs conservation (Murray, 2006, p. iii). Scott, himself is at the centre of the research and Murray acknowledges that analysis of the narratives of Scott's two expeditions, and the contributions of his colleagues is limited by the scope of this thesis (p. 8). The well-trodden path of quoting Markham's welcome speech about the great harvest of scientific results, the list of geographical achievements and collection of information in various scientific disciplines is revisited briefly by Murray (p. 43). Critical analysis of the scientific results is outside the scope of Murray's research, but like Hunt's thesis, it is a valuable background resource.

One scholarly work that aligns with, and informs this research is Salveson's long essay, or mini thesis submitted as partial fulfilment of a M.Phil. in Polar Studies at SPRI, Cambridge (Salveson, 1998). It investigates and compares the scientific achievements of the seven Antarctic expeditions between 1895 and 1905. The criteria used for assessing the success of the expeditions includes data on one hand, and specimens (rocks, fossils, flora and fauna) gathered for taxonomic analysis and to fill museum collections on the other (p. 8). Salveson uses proxies for scientific effort such as the time spent inside the Antarctic Circle, the range of scientific disciplines studied, the number of scientists involved, the publication output and the alignment between expedition objectives and achievements (pp. 9-10). Magnetic research of the *Gauss* and the *Discovery* are included in the geophysical category and viewed together in a positive light:

> They not only equipped themselves with the finest equipment and ships for magnetic work but they also coordinated with each other and other observatories world-wide who were recording term days to gain an understanding of the global variations of magnetic fields.
>
> (Salveson, 1998, p. 28)

Salveson cites Fogg's *History of Antarctic Science* (1992) for description of the observing regimes, but provides little detail. Achievements noted for *Discovery* include Hartley Travers Ferrar's (1879-1932) first geological surveys of the Ross Sea region (p. 32), the 800 pages in three volumes of zoological reports (p. 35) and the discovery of new species of lichens and freshwater algae (p. 39). Salveson briefly discusses polar experience, finance, planning, scientific reports and the use of emerging technologies (pp. 41-48) and states "The British, Swedish and German expeditions coordinated their work during two years through the use of similar instruments, readings, methods of observations, and synchronous timing so that variables could be removed" (p. 51). In conclusion, Salveson refers to the magnetic research thus: "The first high southern latitude magnetic measurements were made, allowing for a scientific postulation of the location of the Magnetic South Pole" (p. 57). Salveson's thesis pre-dates the paper by the magnetic science historian, McConnell, that brings to light deficiencies of the Lloyd-Creak instruments (McConnell, 2005). He was ideally placed as student at SPRI to find all relevant resources but he fails to cite the BNAE *Terrestrial Magnetism* report (Royal Society, 1909) or to include it in his otherwise thorough analysis and tabulation of scientific publication outputs (Salveson, 1998, p. 67). This contribes to scholarship of the early Antarctic scientific exploring expeditions but, as an unpublished thesis, it remains obscure to historians.

A small selection of examples of descriptions of the *Discovery* achievements on web sites is adequate to demonstrate that the generalizations found in print are repeated in electronic sources. The Antarctic Heritage Trust (NZ) gives a concise description of the *Discovery* expedition's main and magnetic observation huts, and Bernacchi's equipment housed within them. The final page comments on the success of the scientific programs and lists of the scientific disciplines investigated. "The National Antarctic Expedition was highly successful. In addition to the comprehensive scientific observations and geographical discoveries described, other research, observations and field work included meteorology, geology, glaciology, botany, marine biology and cartography" (National Antarctic, *Discovery* Expedition, 1901 – 1904, 2012).

The National Library of Scotland website has a comprehensive biography of Wilson that provides some *Discovery* history:

> The expedition carried out groundbreaking meteorological, oceanographic, geological and biological research. They discovered hundreds of new marine species and mapped hundreds of miles of previously unknown coastline, mountain ranges and glaciers. It also reached a record 82º 11', the furthest South any expedition had been thus far. When the research had been analyzed on their return, the resulting body of work was massive. It made up 10 heavy volumes subsequently published by the Royal Geographical Society.
>
> (Edward Wilson [1872-1912], 2012)

For history of the *Discovery,* the SPRI web site links to another web presence, South-Pole.com. It describes the handing over of data and specimens by the scientific staff then reiterates Markham's well aired comments about the harvest of scientific results followed by:

“Truly, this had been the most revealing of all Antarctic exploration as meticulous records were kept on the scientific work” (Robert Falcon Scott: 1868-1912 (n.d). Para. 72). The BBC entry, located in their history pages is succinct, describing Scott’s contribution: “He commanded the Government-funded *Discovery* expedition (1901-4), which undertook significant scientific work” (Flynn, 2011). The *Discovery* itself is the centerpiece of the Dundee Heritage Trust’s museum. The website’s descriptions of the products of the scientific work on the expedition are generous. The results are described as breakthroughs, not just achievements, and:

> The work was truly groundbreaking…The body of work was massive when the research had been analyzed and the Royal Geographical Society came to publish the results, ten large, weighty volumes were filled. It represented a major contribution to the understanding of the Antarctic continent, a feat made all the more remarkable considering the extreme conditions endured by the heroic scientists of *Discovery*.
>
> (Discovery, 2007)

The final word in this category is that found in the Wikipedia entry that states:

> Its scientific results covered extensive ground in biology, zoology, geology, meteorology and magnetism. After its return home it was celebrated as a success, despite having needed an expensive relief mission to free *Discovery* and its crew from the ice, and later disputes about the quality of some of its scientific records.
>
> (Discovery Expedition, 2012)

This selection of web pages is sufficient to demonstrate the majority public view that the expedition was highly successful and that the ten volumes of scientific reports are generally cited as a proxy for successful outcomes.

One last piece of ephemera is worthy of mention. It is an illustrated catalogue published to accompany a recent exhibition of the Royal Collection of Antarctic photographs at the Canterbury Museum, Christchurch, New Zealand. The exhibition was comprised of original prints of many iconic photographs from Scott's *Terra Nova* and Shackleton's *Endurance* expeditions. The catalogue describes *Discovery*'s return: "On *Discovery's* return to New Zealand, and then to Britain, her captain and crew received heroes' welcomes from both the public at large and, more particularly (and importantly), the scientific establishment and the Royal Navy" (Hempleman-Adams, 2009, p. 194).

## 2.7 Honing the research question

The accessible literature addressing the scientific outcomes from the *Discovery* expedition expresses a range of opinion. The majority of commentators describe the expedition as having been scientifically successful. That success appears to have been judged subjectively by quantity of data (meteorological, oceanographic, gravitational, magnetic and auroral) and the range and abundance of specimens (zoological, biological, microbiological and geological) collected. Confusion over the boundary between scientific research and exploratory achievements may be an additional factor. The *Discovery* was the first expedition to penetrate continental Antarctica, and one of the first to establish an overwinter base, so most material collected was novel, and the scientific data was unique. A small number of histories and biographies cast doubt on the value of the outcomes, but these are mainly commentaries on the leadership capabilities of Scott.

There is little evidence in the literature that the magnetic science (or any other discipline) has been analysed critically and few commentators discriminate the difference between magnetic observations on land and those made at sea. Two credible sources comment directly on difficulties with instruments used at sea (McConnell, 2005; Mawer, 2006) indicating scope for further investigation. Most commentators have failed to undertake any deep analysis of the scientific work and its outcomes, and appear to rely on the conclusions of those before them. There is a common perception that the magnetic science of the *Discovery* expedition was highly successful, but there is now sufficient evidence to warrant investigation of the accuracy of this common belief. In nearly all cases statements about success are not based upon a thorough understanding of the scientific program or the scientific contexts of the era and there appears to be only superficial analysis. If there are more robust foundations to these statements, the underpinning criteria are never made explicit.

This review of the reporting of *Discovery's* outcomes suggested two main strands of inquiry for the body of this research. Firstly, there is a place for a deeper critical analysis of the perceptions or measures of success for scientific on early expeditions. Or, expressed differently, what is the full range of indicators of scientific success that might assist an objective analysis of expedition outcomes? The preliminary phases of this research suggested the following list of success indicators:

- Achievement of stated objectives or expectations
- Research carried out within budget
- Research carried out on time
- Access to funding for further similar research
- Promotion, peer recognition or career advancement
- Positive critical reviews and public perceptions
- New knowledge developed or new directions for intellectual inquiry launched
- Data and collections and the discovery of new species
- Detection of valuable natural resources
- Successful collaborations
- Natural phenomena or features named in recognition of scientists
- Technologies, equipment or procedures retained

Secondly, what are the drivers of scientific success? What elements allow some expeditions to achieve excellence in their scientific programs and what factors can undermine well-organised and well-intentioned efforts? The initial exploratory research and review of the historiography of the expeditions of the era suggested a suite of factors, or drivers of scientific success around which the body of this research could progress. They are:

- Historic and cultural context of an expedition
- Patronage, funding and institutional supports
- Leadership and governance
- Preparations
- Instructions
- Collaborative relationships
- Recruitment, training and development of skill and knowledge
- Equipment and instruments
- Logistics
- The work of the scientist
- Social and intellectual landscapes
- Serendipity
- Post-expedition handling and publication of data and collections

Research along the two strands of inquiry, success indicators and success drivers, informed the core supplementary question that asks, with respect to the *Discovery* scientific program specifically, did it achieve it's potential, and if not, why did that happen?

# Chapter 3: Research design

Revealing new knowledge in historic research should not be a chance event. If research is carried out in a random, non-systematic way, without a theoretical basis, how do we know when a defensible version of the truth is reached? This chapter discusses the theoretical basis and the framework that underpins this research. The work was initiated by exploratory research characterised by collection and analysis of a body of historical materials and, although that exploratory research was unstructured, it provided a sufficient footing in the subject matter to develop a set of research questions and potentially fruitful pathways for investigation of Antarctic science in the late Victorian and Edwardian eras.

In order to develop defensible conclusions it was necessary to embark upon the core research using methods appropriate to the subject matter, that were rigorous and that had robust theoretical underpinnings. The research was qualitative in nature and mostly concerned with interpretation of published documents related to the scientific activities of the significant Antarctic expeditions prior to World War I. A framework evolved in the initial stages of research that is thematic in nature and arranged according to the identified drivers of scientific success on pioneer polar expeditions. The research is characterised by detailed analysis of preparations for the *Discovery's* data and specimen collecting activities, the actual data gathering at sea and in Antarctica, and the subsequent analysis and publication of results then conclusions from the scientific enquiries.

This chapter describes the methods used in this research and substantiates their selection and began in the context of the following assumptions:

- The measures of "Success" for scientific programs in the physical sciences of meteorology and terrestrial magnetism can be defined for the pioneering Antarctic expeditions.

- Identified success indicators for the physical sciences are valid indicators of successful expedition science in other disciplines. General conclusions may be possible regarding expedition scientific programs without analysis of every science discipline.
- It is feasible to identify and rank the drivers that led to success in frontier science enterprises and to develop a meaningful discourse on the nature and meaning of science against a backdrop of geographic discovery.

The research progressed on the basis of these assumptions and development of a deep understanding of the scientific activities and outcomes allowed evolution of new knowledge. Jordanova confirms the value of initiating research with some theoretical foundation and some assumptions in her statement: “No empirical activity is possible without a theory, or at least elaborate presuppositions, behind it, even if these remain implicit, perhaps unconscious” (Jordanova, 2000, p. 63).

## 3.1 Research question in context

The set of questions that instigated this research were very general in nature and provided an initial stimulus to the exploratory literature research. A gap in the literature was identified early in the exploratory phase allowing the research to proceed with confidence that the outcomes would be of value and interest to Antarctic historians, scientists and general readers. The research questions that guided the exploratory research included the following:

- Did the *Discovery* meet the stated objectives with respect to scientific research?
- Did the *Discovery* achieve as much as it should and could have given the significant investment and institutional support it had?
- Did other expeditions whose first priorities were scientific, not exploratory, achieve higher quality or more productive scientific work?
- Would the outcomes of the science program on *Discovery* have been different if Professor Gregory had retained his scientific directorship?

Throughout this work the focus was on successful outcomes of Antarctic science and the contexts at the start of the twentieth century were kept in mind to assure the fairest possible assessments according to the standards of the time. Mitigating circumstances such as the extreme environment, the long polar night, cramped working conditions, no access to additional equipment or instruments, limited logistical support for fieldwork and confined social landscapes all influenced scientific productivity and quality on pioneering expeditions. There is an abundance of relevant resources that constitute the foundation or data being analysed, so definition of the scope is an important early step. “Too often beginners state the problem much too broadly, the experienced historian realises that historical research must involve a penetrating analysis of a limited problem rather than a superficial examination of a broad area” (Best and Kahn, 2006, p. 91).

## 3.2 Defining the original sources of *Discovery’s* history

The data sources under investigation are mostly comprised of documents written, and published around a century ago. The publicly available documentary resources constituting the data for this research can be classified into five main categories. They are:

- Private: personal accounts in journals, correspondence and diaries that were never intended for publication or public distribution.
- Official and institutional: formal reports to funding or sponsoring institutions, official correspondence, administrative paperwork, meeting minutes, financial records, ships log books etc.
- Scientific: the outcomes of scientific work recorded in formal expedition science reports, field or lab notebooks, journal papers, learned society lectures and meetings and sometimes as significant elements of expedition narratives.
- Public: expedition narratives, media reports (in this case primarily newspaper reports), lectures (both pre and post expedition), museum exhibits and promotional ephemera such as postcards.

- Secondary analyses: sources such as monographs, texts, journal articles, lectures and media productions (radio, television and electronic resources) that analyse or provide commentary on the activities or people engaged in the expeditions of interest.

There is an alternative typology for classification of sources that relates to their proximity to the events that are the objects of the research. The division of sources into primary and secondary categories is required for discrimination of the importance or value of them to the process of inquiry, especially during the data gathering stage of the research. Cohen and Manion refer to primary sources as “the lifeblood of historical research” and secondary sources as supplemental to the primary data (Cohen and Manion, 1994, p. 50). They split primary sources into two further sub-categories. Firstly, remains or relics that include tools, buildings and pictures. These artefacts are examples of material items where the load of meaning invested in the artefact increases through time. These remains may have almost religious significance for avid followers of the significant figures of Antarctic exploration (Hodder, 1994, p. 393). Secondly, items with a direct physical relationship to the events being reconstructed include written or oral testimony by the participants and documents such as manuscripts, records, letters, memoirs, biography, official publications, newspapers, magazines, maps, diagrams, film, log books and research reports (amongst others).

Secondary sources do not have a direct physical relationship to the events being studied and are generated by persons who obtained descriptions from another person or source (Cohen and Manion, 1994, p. 50). This means secondary sources are accounts of an event not actually witnessed by the reporter (Best and Kahn, 2006, p. 91). Examples of secondary sources include monographs, textbooks, reproductions of material, journal articles and commentaries on events and chapter two is based on such sources.

Some sources for this research are facsimile editions of expedition narratives. These contain contemporary introductions by editors of the new editions, but are otherwise identical in content to the original publications. In these cases the introductions are viewed as secondary sources whilst the facsimile is considered a primary source. The nature of the data places this research firmly within the realm of qualitative research. Some numerical information is provided as a means of summarizing characteristics of certain expeditions only. The sources used in this research provide a rich textual background to the scientific work through the numerous personal diaries, journals, annotations in sledging records and in personal correspondence.

## 3.3 Theoretical framework

A generalised model of the processes required to complete a research project in the social sciences is provided by Punch (1998, p. 42) and is shown at Figure 1. It relates to the formation of the research question as well as the manner in which it is investigated. This simplified model addresses operations and processes, but fails to address any theoretical background in the realm of historiography of the sciences. The remainder of this chapter addresses the deficiency through discussion of the theoretical background, then the methodology, methods and processes that structured the thesis research.

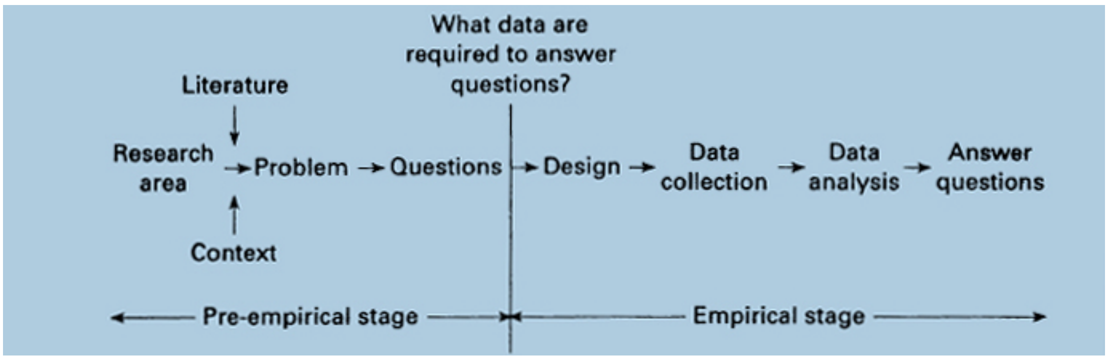


Figure 1: Elements of the research process (Punch, 1998, Figure 3.1 [a], p.42).

This research was an iterative process similar to that described by Polkinghorne, with two operations. First is the collection of evidence and second is analysis and interpretation of that evidence. “Narrative researchers frequently move between these two performances choosing further sources of evidence based on the needs derived from interpretations of the already gathered evidence” (Polkinghorne, 2007, p. 478). The core of data now exists for this research and is comprised of documentary evidence such as scientific reports, official expedition narratives, journals of mariners and scientists, and the commentaries upon them. In accord with Cole’s belief that: “Historical research reveals the pervasive influence of social, political and cultural factors on the conceptual bases of scientific thought” (Cole, 1997, p. 47) the exploratory research for this project identified social, political and cultural factors as contributors to success of expedition science.

### 3.3.1 Epistemology and ontology

Establishing the epistemological basis for the research process provides a philosophical underpinning by which to recognise when knowledge or truth is acquired or identified. There are three dominant epistemological stances (Crotty, 1998, pp. 8-9).

- Objectivism is a belief that objects have innate meaning in their own right. It is an episteme that articulates with the methods and methodologies of the natural sciences. The paradigms of positivism and post-positivism operate within the epistemology of objectivism and rely on a process of hypothesis testing through experiment or hypothetico-deductive enquiry.
- Constructionism is the episteme operating on the belief that truth comes into being through the engagement between the observer and the world. Subject and object both contribute to the construction of meaning. The researcher is the subject and the object is the item undergoing analysis. Meaning is constructed rather than discovered, and different observers may construct different realities in relation to the same object or phenomenon.
- Subjectivism is the third dominant episteme whereby the object does not contribute to the generation of meaning. The act of observing imposes meaning on the object that may be inspired by prior experience, beliefs or thoughts. The

generation of meaning is therefore completely subjective and totally reliant on the observer.

This research operates from a philosophical stance of constructionism. The selection of source materials for the research, their classification, their interrelationships and the meaning distilled from each item of information carry some subjective bias of the researcher. Each item of data also carried some innate meaning derived from its development, whether it's a document, an artefact or a set of scientific data for example. The interplay of those elements resulted in the generation of new knowledge throughout this research. Literature concerned with epistemology frequently deals with ontology at the same level of theoretical perspective. Ontology is the analysis of how we understand *what is,* compared to *what it means to know* in the case of epistemology (Crotty, 1998, p.10).

Previous researchers have already undertaken the process of locating, annotating and analysing many, or all of the documents that make up the body of the research data. This does not diminish the value of this research, as many different versions of the truth are possible in history and reevaluation of data from alternative perspectives may lead to a different truth. Carr, in his landmark collection of essays entitled *What is History?* argues that any historic analysis will reflect the historian's bias and cannot be objective, and he argues the case that there are multiple versions of truth that may be derived from one set of data. Historical truth lies between valueless facts and value judgements (Carr & Evans, 2001, p. 126). Personal bias may be introduced at any stage of the research process from framing the research question(s), the development of the research framework, selection of data sources, their interpretation and the manner of reporting in the final thesis document.

Hexter argues the case that some forms of historical reporting can be objective but these so-called "true narrative explanations" do not provide an adequate historical story. The craft of the historian is to relate a story: "truest to the past, determined by the rules of historical evidence and the rhetorical rules of historical storytelling." Hexter's example demonstrates that an objective version of a history, relating facts only, results in poorly written narrative that disregards context and causal factors (Hexter, 1972, p. 34). He agrees with Carr that it is essential to know something of the historian's background when judging a particular version of history. He cites an example that demonstrates that, with discrimination, it is possible for a reader to find an accurate version of a history untainted by bias of the writer (Hexter, 1972, pp. 103-106).

History is an epistemologically fragile discipline for four reasons. The content of history is virtually limitless and a historian cannot recount more than a small portion of it. No account of the past can be verified for absolute authenticity. History remains a personal construct that is influenced by personal predilections and viewpoints. History is written retrospectively by practitioners with knowledge that would have been unavailable at the time of the events, and that may distort the interpretation of events (Jenkins & Munslow, 2003, pp. 13-16). The development of sophisticated thinking about the history of science grew from the belief in the nineteenth century that philosophical reflection could provide a general framework for that branch of history. Jardine describes the development from the rationalist thinking of William Whewell (1794-1866) through to the more recent debate amongst Thomas Kuhn (1922-1996), Karl Popper (1902-1994) and others over the mechanisms and philosophy of the history of science (Jardine, 2005, pp. 287-296).

### 3.3.2 Paradigms

A paradigm is: "A comprehensive belief system, world view or framework that guides research and practice in the field" (Willis, Jost & Nilakanta, 2007, p. 8). Although it is appropriate to use multiple methods within a research task, the work becomes meaningless if the research processes have no paradigms to provide guiding principles. A suitable paradigm developed according to the nature of the research data sources, the nature of the enquiry and the manner in which data was aggregated and ultimately reported. The central paradigm informing this research is the "Interpretive" paradigm. It is concerned with interpreting events and understanding situations from the participant's rather than the researcher's perspective. It concentrates on local understanding of events and their cases. Interpretivism is a paradigm that operates in social sciences that rejects the research methods and empricism of the natural sciences (Willis et al, 2007, p. 54). Willis further adds: "Interpretivism proposes that we abandon the search for generalizable truths and laws about human behavior and concentrate instead on local understanding" (Willis et al, 2007, p. 61). The interpretive paradigm presupposes that knowledge is built with an understanding of the content and it is concerned with the creation of meaning. It aims to develop an understanding of how people make sense of their experiences by interpreting events, contexts and situations. The core belief of interpretivism is that reality is socially constructed, is multilayered and complex and the researcher acts as the primary instrument for both data collection and analysis and multiple interpretations (all valid) of single events are possible. Interpretive research is richly descriptive as it is concerned with process, meaning and understanding. The two threads of interpretivism are firstly, that the experience of the senses (empiricism) is not always the best way of knowing, and secondly, that the reality that we perceive is always conditioned by our experiences and our culture (relativism). Relativism is also known as antifoundationalism as there is no secure foundation that humans can use to discriminate truth from untruth (Willis et al, pp. 48-49). The use of a case study accords with the interpretivism paradigm and this is consistent with the inductive mode of inquiry used throughout the research to construct new knowledge.

### 3.3.3 The diachronical approach

The intellectual landscape for academic and professional scientists in the Edwardian era was unlike the present and judgements made regarding the conduct of scientific processes on expeditions using current standards may lead to misguided conclusions. This anachronical view, that the science of the past ought to be studied in the light of knowledge that we have today, is an uncommon historiographical strategy (Kragh, 1987, p. 89). In keeping with the interpretivist approach, this research endeavours to make judgements of scientific and other matters in the context of the time of the events. This mode of interpretation is labelled the diachronical approach in which the historian is:

> …not interested in evaluating the extent to which historical agents behaved rationally or whether they produced true knowledge in an absolute of modern sense. The only thing that matters is how far the actions of the agent were judged to be rational and true by the agent's own time.
>
> (Kragh, 1987, p. 90)

This approach has also been labelled contextualism and described thus:

> For want of a better word, "contextualism" seems to have emerged as a positive label for the doctrine that one should study the ideas and theories of a period in terms of the scientific knowledge of that period, without regard for what came afterwards.
>
> (Brush, 1995, p. 219)

This idealised standpoint intended to generate fair appraisals of the quality of scientific activities in a previous era was adopted for this research, but there are some circumstances in which the diachronical approach must be abandoned if fair appraisals of the total impact of a scientific activity are to be judged. Scientific discoveries that overturned existing paradigms, boosted the careers of scientists, opened new lines of inquiry paving the road to other significant findings or, that went unrecognised as significant at the time, warrant analysis using the broader context of an anachronical approach (Kragh, 1987, p. 106).

## 3.4 Methodology

Methodology is the structure or logic that leads to the choice of methods. It describes the elements of research design, data collection, analysis and interpretation. Crotty defines methodology as "…the strategy, plan of action, process or design lying behind the choice of particular methods and linking the choice and use of methods to the desired outcomes" (Crotty, 1998, p. 3). This research uses multiple, complementary methods as a means to make the study more complete.

### 3.4.1 History and historiography

This section clarifies the terms "history" and "historiography" and the nature of the work of the historian. Seeking historical truths by gathering, then ordering sets of facts from various sources is a fundamental process of historical research. A chronological description of events, or themes of an event is inadequate when the intention is to test ideas and develop a new interpretation, or a deeper and enhanced understanding of an activity or process. Such a chronological (or otherwise arranged) account of events provides the raw material for theoretical reflection on the nature of history, in this case frontier polar expedition science**.** The work of the historian is: "To acquire the necessary background-not only to learn the dates, names, and key events, but also to master controversies amongst historians about whether, how and why those dates, names and events matter" (Tuchman, 1994, p. 314). This means finding sufficient reliable, relevant documentary or other evidence related to the topic under investigation. This evidence then informs interpretation of causal relationships between the factors regulating scientific productivity and quality in the case of this research. Kragh distinguishes between two common meanings of the word *history*. It can describe the actual phenomena or events that occurred in the past; that is, objective history, or it may be "the analysis of historical actuality, that is, of historical research and its results" (Kragh, 1987, p. 21). There is also ambiguity in meanings of historiography. One version is: "The term "Historiography" has increasingly been used to mean the history of history writing: in effect, a branch of intellectual history or a sub branch of the sociology of knowledge (Hexter, 1972, p. 15). In this sense it is a form of meta-analysis of prior effort in researching and reporting a topic. It involves investigation of the range of opinion concluded by other historians and the justifications for those conclusions. This process is relevant to the literature review process of this research but less so to the main body of the research. Hexter adopts the term historiography to mean the craft of writing history and/or the yield of such writing considered in its rhetorical aspect and Willis states it simply: “All the methods of history research are called historiography” (Willis et al, 2007, p. 259). Historiography can therefore be classified as one methodology in the hierarchy of elements of research theory, design and practice. The ambiguity of definitions of historiography is reviewed in Kragh’s monograph that specifically concerns the historiography of science (Kragh, 1987, p. 21). One meaning relates to professional writing about history. In this first interpretation the descriptive or objective history becomes the object of historiographical analysis that leads to deeper understanding. Her second meaning relates to a deeper study that involves the theory or philosophy of history, or theoretical reflections on the nature of history. This research adheres to the style of historiography promoted by Hexter and Willis and the first of Kragh’s interpretations.

### 3.4.2 Inductive reasoning and analytical induction

The research progressed using inductive processes that accord with the interpretivist approach. These processes are characterised by the search for meaning within disconnected qualitative data in a manner where interpretations were developed during the analysis (White, 1978, p. 45). This process accords with inductive reasoning in which new theories or concepts are constructed after recognition of patterns within the data. Deductive processes, by contrast, are those where a theory or hypothesis is proposed at the outset of the research, then a series of controlled experiments are conducted to support, or disprove the hypothesis or statement. The methods of deductive processes are generally quantitative in nature and are unsuitable for this research. A historical event cannot be repeated although events that have common elements or similarities may be compared.

Analytical induction is a strategy for generating knowledge, rather than a research method. It commences with a question or problem and the purpose of the research is to deal with the problem. It involves a series of steps in data analysis that move from raw data towards possible answers or solutions and it is a process suitable for qualitative or quantitative analysis and may involve a multi-case approach. It is iterative and commonly involves the following steps:

- Data collection
- Data analysis from which a descriptive or explanatory model is developed
- Gather data from another case
- Apply the model to the new case
- Revise the model if necessary
- Complete the steps (looking for new cases that challenge the model)

(Hicks, 1994, p. 88)

Analytical induction has elements in common with grounded theory (described below). Both methods are recursive and both may have ideas, categories or a focus that change during the research. New theories or hypotheses may develop out of the research in either case. The process of constant comparative method (Strauss & Corbin, 1994, p. 273) may be used in either grounded theory or in analytical induction. An important difference is that grounded theory does not necessarily progress to new cases whereas it is essential in analytical induction to do so.

### 3.4.3 Elements of grounded theory

Grounded theory is a general methodology used in the social sciences and is a distinctive research strategy aiming to generate explanatory theory grounded in data that is generally qualitative in nature (Strauss & Corbin, 1994, pp. 273-275). Grounded theory analysis refers to specific procedures in the analysis of data for the generation of explanatory theory and focuses on raising the conceptual level of the data (re-conceptualising). Open coding is one step in the process by which such analysis may be undertaken where each item of data is classified in response to the general question "What is this piece of data an example of?" Substantive codes emerge and relationships between the items of data can be identified later. Emergent patterns can be interpreted to develop theory or explanation. Axial coding is a process of consolidating or clustering the items of open-coded data into groups or sub-sets. These new groups represent higher conceptual levels of data and explanatory theory might be suggested by these aggregations. This approach has been used to good effect in the detailed analysis of polar diaries by Mocellin and Suedfeld (1991) to draw conclusions about the psychological state of early expeditioners in relation to the level of hardships they endured.

Grounded theory links data to theory directly, and the data drives the development of that theory. The following evaluation criteria were used when generating themes, conclusions or theories from the data.

- Parsimony: does it provide the simplest explanation that is meaningful?
- Scope: how broad is the theory? Can it be applied to a range of contexts?
- Overall explanatory power: how much of the situation does the theory explain?
- Degree of generalization: does at least some of the theory seem helpful when applied to similar situations?
- Logical internal consistency: does it hang together?

(Willis et al, 2007, p. 307)

Deeper understanding of the events under analysis during this research has been made possible by application of a system of classification to items of data in a routine of open, then axial coding. One process derived from grounded theory that has been applied during this research is the constant comparative method, in which steps relate directly to the routines of open coding and axial coding. The method has six steps and is recursive: Start data collection, organise data into units, associate similar units and categorise, look for links, associations and relationships between categories, develop broader, more general explanations from the categories and their relationships, then repeat the routine (Willis et al, 2007, pp. 306-307).

### 3.4.4 The unit of analysis

Within the main body of this research the unit of analysis that defined the open coding categories was an event that that constituted part of the cycle of scientific research on the expedition. Examples included pre-expedition arrangements and preparations, the performance of scientific operations and the actions of post-expedition analysis then publication. They were as broad as the action of fundraising, or as specific as the operation of taking magnetic readings during a sledge journey. They all contributed to the ultimate scientific outcomes. Although the focus was on *Discovery* the other expeditions of the era on which notable magnetic science work was identified were also investigated throughout the research. These expeditions of the era are tabulated in Appendix I and cover the period between 1897 and 1914. Twelve categories of indicators of scientific achievement were identified during the exploratory research (see Section 2.7) and coding of documentary evidence proceeded accordingly. Examples from scientific disciplines other than terrestrial magnetism were also used to demonstrate particular points.

## 3.5 Methods

Methods are the operations used to collect and analyse data. Their selection depends on the types of data being analysed and the type of knowledge generation anticipated. They are the pragmatic tools utilised in the collection and analysis of data. Note that: "History does not operate in a closed system such as may be created in the physical science laboratory. The historian cannot control the conditions of observation nor manipulate the significant variables" (Best and Kahn, 2006, p. 87).

Although much of the subject matter of this research is the result of scientific research, the methods common to the natural sciences are unsuitable for research in the social sciences. This research is qualitative in nature and is concerned with the collection and analysis of the documentary evidence and sources relating to the work of Antarctic expeditions under review. The relationships between the theoretical framework and the methods and process of the research are shown in Table 1 that represents the manner in which the elements of epistemology, theoretical perspective, methodology, methods and processes inform one another (Crotty, 1998, pp. 4-6).

| Epistemology | Paradigm | Methodologies | Methods | Processes |
|---|---|---|---|---|
| Constructionism | Interpretivism | Historiography | Documentary analysis | Define questions |
| | | Grounded theor | Open and axial coding | Identification of data sources |
| | | Analytical induction | Constant comparative method | Data collection |
| | | Inductive reasoning | Interpretive Case Study | Historical criticism |
| | | | Writing as inquiry | Development of themes, theories or conclusions |
| | | | Biography | Testing themes, theories or conclusions |

Table 1: The theoretical research framework demonstrating the relationships between theory and process.

### 3.5.1 Documentary analysis

The central task of this research involved accessing, recording and analysing the contents of numerous items of documentary evidence. The richness of the descriptions and analyses of events and activities related to the scientific activities provided abundant material for analysis. Particular note was taken of sources grounded in the setting (or context), reported successful scientific outcomes, demonstrated challenges encountered in the process, or that explained failure.

The exploratory research revealed official scientific reports as rich sources of knowledge related to elements of the success of expedition activities, but the scientific reporting is objective in nature and relates facts with little context. There are some exceptions where the work of other expeditions is reviewed in introductory chapters of reports. The official narratives are generally chronologically arranged lists of activities and events that rarely describe the social landscapes of expedition life. They have generally been published as popular literature soon after the expedition's completion and therefore neglect conclusions from the scientific work, as scientific results generally require extensive analysis before conclusions can be made and published, in many instances years after the expedition. Within the first-hand accounts in personal journals, diaries, letters and even column notes in logbooks, the rich textures of the social landscapes can be found and interpreted. As the events being analysed occurred around a century ago there are no survivors of these expeditions to interview although there are rare examples of oral histories relevant to this work like the interviews between the author Lennard Bickel and Webb from the AAE (Webb, 1975). The literature review itself was an element of the research process. It functioned to position the research in the context of similar works and significantly, it represented the commencement of data location and gathering, and the discrimination of the relevance of the sources to the central questions under analysis.

### 3.5.2 Interpretive case study

Although this research used one expedition as a case study, comparison against elements of other expeditions enhanced the authenticity of conclusions. Merriam gives one interpretation of how a historical case study might be characterised:

> This type of research employs techniques common to historiography-in particular the use of primary source materials. Historical case studies may involve more than a chronological history of an event…To understand an event and apply one's knowledge to present practice means knowing the context of the event, the assumptions behind it, and perhaps the event's impact on the institution and participants.
>
> (Merriam, 1998, p. 24)

An alternate classification of methods is based on the way in which the data is used. The "interpretive case study" is a method to gather and analyse thick data sources. Such studies go further than descriptive studies by developing conceptual categories, by demonstrating support or challenging theoretical assumptions held prior to the data gathering (Merriam, 1998, p. 28). The focus is on understanding the intricacies of a particular situation, setting, organisation, culture or individual, but that local understanding must be related to prevailing theories or models. Merriam further defines case study as: "An examination of a specific phenomenon such as a program, an event, a person, a process, an institution, or a social group" (Merriam, 1998, p. 9). Characteristics of the case study central to this research are that the data is thick and descriptive, that the processes involved are inductive and generalizations, concepts and theories emerge from examination and analysis of the data.

Case study is suitable for development of a full, rich understanding of the context of the study, based on Max Weber's (1864-1920) concept of *verstehen* in the social sciences (Willis et al, 2007, p. 240). This deep understanding is generally attributed to participant observation during social science research (Platt, 1985. p. 448) but this research had a goal of developing deep understanding of events (the objects of research) rather than understanding responses of study participants. There is some cross case analysis in this research for assessment of what acceptable levels of scientific performance were in the era under investigation. This research is essentially an interpretive case study that uses coding tools borrowed from grounded theory as a mechanism to keep processes of documentary analysis systematic.

### 3.5.3 Writing as inquiry

Writing as a process can allow reflection on ideas that develop during analysis. Writing as a method in research is virtuous: "Through writing, we usually process what we have discovered in the archives and, as we write, both generate new questions and see the holes in our research thus far" (Curthoys and McGrath, 2009, p. 48). It is an iterative process that is reflective in nature and allows development of themes as patterns become evident within the data. Placing thoughts to paper provides the substance for review and reflection and leads to clarity of argument. Writing as a method can lead directly to new knowledge: "Writing is also a way of 'Knowing'-a method of discovery and analysis. By writing in different ways, we discover new aspects of our topic and our relationship to it. Form and content are inseparable" (Richardson, 1994, p. 516). Writing for different audiences, for example using the same material for a thesis chapter, a journal article, a magazine article or a conference presentation can bring out different elements of the topic and clarify understanding of the important features of the matter under analysis. Richardson provides practical guidance regarding conventions, formats and practice in the process of writing in the social sciences (1994, pp. 519-524) that add further utility to writing as a research method.

## 3.6 Other Considerations

### 3.6.1 Historical criticism

Historical criticism is the essential process of evaluating the worth of source material of data. Cohen and Manion describe the process for the historical researcher thus: "Evaluation of historical data and information is often referred to as historical criticism and the reliable data yielded by the process are known as historical evidence" (Cohen and Manion, 1994, p. 52). It falls into two main categories: external criticism is the process whereby the data is checked for authenticity while internal criticism is the process of determining the accuracy and worth of the data (Cohen and Manion, 1994, pp. 52-53). During data gathering for this research the criteria of authenticity and meaning were considered when locating potential sources and their contribution (Scott, 1990, pp. 19-28). This study referenced multiple sources describing single events wherever possible to promote reliability of facts, to add value to interpretations and to ensure defensibility of conclusions.

### 3.6.2 Feasibility

Research activity into the history of science must be informed by consideration of questions regarding the suitability of the researcher to the task. Is a scientist well equipped to undertake a rigorous piece of historical research and, is it necessary for the researcher working in the realm of the history of science to have any scientific training? Brush addresses these questions in depth concluding that:

> Scientists should write history of science if they are willing to acquire the skills and background knowledge of the historian of science; and the non-scientist historians should write history of science if they are willing to learn enough about science to understand what they are going to write about.
>
> (Brush, 1995, p. 215)

Additional threats to the authenticity of conclusions of this, and any other historical research included documents in languages other than English (such as the *Gauss* [German], *Antarctic* [Swedish] and *Pourquoi-pas?* [French] expeditions), limited access to materials in private collections, incomplete records, unfound but relevant documents and finally documents censored or sanitised to avoid embarrassment by the author or family. The author's topic knowledge and familiarity with the range of relevant resources was critical in determining representative samples and those that were likely to yield new knowledge. Every effort has been taken to overcome risks presented by these factors and to ensure as much relevant material has been acquired within the constraints of the period of candidature. In addition, the work of the historian may not necessarily be entirely systematic as it is probable that new lines of enquiry open up throughout the research process and new resources may unexpectedly come to the attention of the historian also. Advantage has been taken of opportunities presented in this manner.

### 3.6.3 Objectivity

This research aims to create a modern reconstruction or re-interpretation of past events. Genuine objectivity is not possible due to bias of the researcher, bias of prior commentators and authors, the variable nature of the truth in history and the impossibility of confirming events as fact when participants are long dead. Triangulation of sources and cross-referencing personal accounts of events are strategies that assist arrival at the most authentic version of the truth of an event possible. Best and Kahn warn that a risk of historical research is "The tendency to accept the truth of a statement if several observers agree" (2006, p. 98). Reiteration of published errors of fact, or unsubstantiated opinion in the realm of Antarctic history may be due to the proliferation of publications that feed the public fascination with heroic deeds and figures. There are also examples among the official expedition narratives where bias is introduced through omission or misleading versions of events.

### 3.6.4 Authenticity

There are four possible versions of history that may be extracted from the accessible sources for this dissertation and caution must be used when analysing their significance and veracity. They are:

- Official or institutional history: formal reports to funding or sponsoring institutions, official correspondence, administrative paperwork, meeting minutes, financial records and the like.
- Public history: expedition narratives, media reports (in this case primarily newspaper reports), lectures (both pre and post expedition) and promotional ephemera such as postcards.
- Private history: personal accounts in journals, correspondence and diaries, not intended for publication.
- Scientific history: the outcomes of scientific work recorded in formal expedition science reports, field or lab notebooks, journal papers, learned society lectures and meetings and sometimes as significant elements of expedition narratives.

The criteria of authenticity, credibility, representativeness and meaning were considered when analysing the potential contribution of sources (Scott, 1990, pp. 19-35). This study used multiple data sources wherever possible to ensure data authenticity and robust conclusions. An additional element promoting authenticity is the first hand experience of the candidate in polar scientific fieldwork, oceanography between Tasmania and Antarctica and square-rig sailing that combine to provide an acute contextual understanding of the subject matter of the research.

## 3.7 Models of research and scaffolding

Many accounts of expeditions from the late Victorian and Edwardian era of Antarctic exploration have simple, chronologically sequential, descriptive narratives. Others take a biographical approach and focus on key protagonists such as Scott or Shackleton. This research takes a fresh approach through deep analysis of scientific activities of expeditions and their intellectual and physical output. Although the core chapters are still related in a chronological sequence (to avoid a haphazard narrative style) the research is organised around investigation of the set of success drivers of the science programs. The analysis was inspired by models of the development of colonial science proposed by Basalla (1967) and MacLeod (1982). Basalla proposes a simple model describing three stages in the development of science in colonies (metropolitan, colonial then independent) with each representing a greater degree of autonomy (Basalla, 1967, p. 611). Antarctic science in the late Victorian and Edwardian eras mimics the first two stages. The first is characterised by collection and description. The second sees the emergence of an expanded range of scientific activities that eventually coincides with the spectrum of disciplines in the countries that are supporting the frontier scientific endeavours. The third phase is the emergence and consolidation of an independent colonial scientific culture (Basalla, 1967, pp. 613-617). MacLeod expands Basalla's model (considered simplistic) to a five-phase model developed with consideration of social and political influences (MacLeod, 1982, pp. 7-14). The early twentieth century fits into Macleod's "Efficient Imperial Science" phase characterised by scientific activities related to resource extraction at the periphery (that is, the colonies or Antarctica) and theoretical science seated firmly in the metropolis. Inkster (1985) reviews the models and distinguishes between three levels of support for scientific enterprise. These models were developed and applied in another thesis in the realm of history of science that analysed the early development of astronomy in colonial New South Wales:

> ..first, the scientific superstructure which involves aspects such as the availability of trained scientists, laboratories, instruments and research programmes; secondly, the socio-economic base which provides the economic capability of supporting science given the existence of a more or less stable society; and thirdly, in between these two levels, and mediating them, is the cultural/institutional infrastructure.

(Saunders, 1990, p. 3)

There are parallels between Antarctic expedition science and science in remote developing colonies. The isolation of the Antarctic expeditions far from the control of the institutional sponsors is analogous to the new colony of New South Wales a century earlier, in a time when an official communication and response by letter could take twelve months. Antarctic science in the Edwardian era differs from colonial science model in respect of the emergence of colonial scientists that ultimately break away from central control as no permanent colonial settlements were established in Antarctica until the 1950's.

An additional model for this research was provided by Endersby's treatment of the nature of Imperial science (Endersby, 2008). He makes a thorough analysis of the elements of frontier science by close investigation of the actual procedures, processes and methods of botany in the metropolis (Kew Gardens) and at the periphery (Australia and New Zealand). This model stresses the maintenance of the intellectual analysis at a central location and the specimen and data collecting in the field, at the periphery. Control by the institutional arrangements or powerful figures, in this case Joseph Dalton Hooker (1817-1911), perpetuates the intellectual divide between metropolis and periphery (Endersby, 2009). The new knowledge generated by this research in relation to Antarctic science in the late Victorian and Edwardian eras was developed through detailed analysis of the scientific work at sea and on the ice following Enderby's model.

Many of the drivers of scientific outcomes are closely interrelated in most examples making their compartmentalisation within the thesis complex. One example is the difficulty separating the institutional support from the RN, RS, RGS and British Government from the task of arranging the funding of the *Discovery*. There were elements of power and control, national pride, territorial aspirations, conflicting agendas of key figures and the practical questions of settling on agreed expedition objectives. These elements were overlaid by the themes of how preparations for the expedition progressed and how and why staff were recruited. In historical research:

> Often it is more difficult to discern patterns in qualitative data than in quantitative data, but qualitative data are richer: They are more likely to be meaning-ful(l)-more likely to let a researcher see how a social world seemed and felt to a variety of its members.
>
> (Tuchman, 1994, p. 312)

The product of this research is in narrative form. Studies of events and activities on the *Discovery* have been used as lenses to focus on the elements of interest that address the research question. Presention of research findings in themes and typologies is consistent with scholarship using the interpretive paradigm. The narrative form also allows clarity to ensure unambiguous and meaningful interpretation of the work by readers that may not have a deep knowledge of the subject matter.

In summary, the body of this research analyses the operations and outcomes of the scientific programs in the discipline of terrestrial magnetism on the *Discovery*. Exploratory research was undertaken that raised doubt about whether the *Discovery* expedition achieved the scientific quality and productivity that it could, and should have, given the background from which the enterprise evolved. The research design is based on inductive processes and the theoretical framework follows the episteme of constructionism and the interpretivist paradigm. The methodology of historiography using techniques of analytical induction and inductive reasoning were applied research methods included documentary analysis, open and axial coding, constant comparative method, interpretive case study, writing as inquiry, and biography. The data sources are primarily documentary in nature and focus on publicly available reports and narratives related to the science programs of the expeditions.

The initial data collection, then analysis was guided by the themes of the drivers of scientific success that were developed during the exploratory research and inspired by models related to developments in colonial Imperial science. The thesis narrative is the primary source of evidence demonstrating that the candidate has undertaken meaningful and effective research, a learning process has occurred, new knowledge has evolved and mastery of the subject matter has been achieved. This chapter is evidence of the research's theoretical foundation and the rigor and integrity of its processes. The following chapter provides an overview of the historic, cultural and scientific contexts when the preparations for *Discovery* commenced, then describes the start of expedition planning and organisation.

# Chapter 4: Historic and cultural contexts

The scientific, historic and cultural landscapes of the late Victorian era influenced the ways in which science was planned and performed on the *Discovery* expedition. The (separate) instructions to the expedition commander and the director of the civilian scientific staff set practical logistical agendas and benchmarks for the ultimate assessment of outcomes. Comprehension of the social and cultural contexts in Britain at the close of the nineteenth century inform the understanding of motivations and processes in the expedition's evolution. Markham's extensive memoirs (Markham & Holland, 1986), detailed personal notes (Markham, n.d.b; Markham, n.d.g) and correspondence recall the personal and institutional challenges he faced in his quest to launch the new era of Antarctic exploration that resulted from the resolution of the 1895 World Geographical Congress (Keltie & Mill, 1895).

## 4.1 Contexts

### 4.1.1 Empire

At the end of the nineteenth century Britain ruled large tracts of the known planet. The Empire extended over a quarter of the world's land surface and in the twelve years prior to 1899, Great Britain had territories equal to twenty four times its own area. Eighteen ninety seven was the jubilee year for Queen Victoria and the public rejoicing peaked on 22 June when eleven colonial premiers joined millions of happy people who cheered and waved "in an ecstasy of love and pride" at the procession of "cavalry from every quarter of the globe" that was followed by the Queen herself (Tuchman, 1966, pp. 54-56). The turn of the century marked "The end of the most hope-filled, change-filled, progressive, busiest and richest century the world had ever known" (Tuchman, 1966, p. 58). The German Krupp armaments manufacturing capability was swelling (Tuchman 1966, p. 229) and the Russian Tsar, realising that the arms race was unaffordable and could not be won by Russia, was trying to negotiate a European pact to prevent, or at least slow the pace of competing arms production. International arms limitation talks during the first years of the new century failed to prevent the inevitable conflict in Europe.

### 4.1.2 Class and the rise of socialism

Queen Victoria's death on 24 January 1901 ushered in a new, less conservative era amongst the sporting set, of which the Prince of Wales, (crowned King Edward VII in 1902), was a central figure. Within the two hundred families that had been governing England for generations everyone knew, or was related to one another. The King's social group was considered vulgar by some intensely class conscious, long established families (Tuchman, 1966, pp. 19-20). The upper classes partied but the lower classes were despondent. Britain had been suffering economic depression during the 1890's. The first great dockworkers strike of 1899 threatened international trade and income to the wealthy as did competition from abroad that threatened British supremacy in foreign commerce (Tuchman, 1966, p. 352). Social unrest was characterised by three factions: "Trade Unionists wanted a legal right to strike, Socialists wanted to nationalise property and Anarchists wanted to abolish it" (Tuchman, 1966, pp. 4-5).

### 4.1.3 Industrial and scientific revolution

The nineteenth century was a time of rapid scientific, intellectual and technological developments and those relating directly to the preparations and operations of the *Discovery* are reviewed here. The capability and safety of ships bound for polar regions in particular was advanced by the invention and patenting of the screw propeller in 1835 (Kemp, 1979, p. 671). Metallurgy and the evolution of reliable and powerful steam power were legacies of the industrial revolution that characterised nineteenth century Britain. As an example, the *Erebus* and *Terror* were fitted with steam locomotive engines of about 20 horsepower for Franklin's (1845) Northwest Passage expedition (Rondeau, 2010).

Publication of the theory of natural selection as a mechanism of evolutionary change developed separately by Charles Darwin (1809-1892) and Alfred Russell Wallace (1823-1913) brought about a paradigm shift for most of the British population where the immutability of species and divine creation were replaced by an understanding of the antiquity of the earth. The natural sciences started to shift away from mere cataloguing and description, and: "Science took away belief in God and certainty in a scheme of things…" (Tuchman, 1966, p. xiv). The life works of the eminent geologist Charles Lyell (1797-1875) culminated in publication of *Principles of Geology: An Attempt to Explain the Former Changes of the Earth's Surface by Reference to Causes now in Operation* in 1830 and its subsequent twelve editions, the last being published posthumously in 1876. Lyell's works explained many elements of earth's prehistory including glacial epochs, and founded the nomenclature for describing the recognizable phases of development in the fabric of the geological landscape and the nomenclature of stratigraphy still in use by geologists. Lyell affirmed the conclusions of Darwin (Encyclopedia Britannica, 1911). Ferrar, the geologist to the *Discovery* expedition, would have studied the works of Lyell in great detail during his studies in Cambridge (New Zealand Journal of Science and Technology, 1932).

The American professor, Samuel Morse (1791-1872) invented the telegraph in 1837 and his "Morse Code" the following year. By the 1860's America had a transcontinental service. Expedition organisation and logistics were influenced by the utility of telegraph that allowed communication between Britain and the antipodes via overland and undersea cables installed progressively after 1866 (Abbot & Glass, 2010). Correspondence between Markham in London and Scott in Christchurch was possible, making the reach of control from the metropolis far greater than for expeditions prior to the *Challenger* of 1872.

The 1890's ended a period of ferment in industrial and scientific developments. Britons: "…entered the twentieth century with his capacities in transportation, communication, production, manufacture and weaponry multiplied a thousandfold by the energy of machines" (Tuchman, 1966, p. xiv). Scientific instrumentation improved during the nineteenth century through better design, metallurgy and machining. The state of practical and theoretical knowledge in the science of terrestrial magnetism follows at section 4.3.

#### 4.1.4 Royal Navy

The RN was an instrument of Empire and had many subsidiary duties to fulfill besides defense. Constant readiness to go anywhere and do anything was a basic requirement of the service but its pre-eminence was fading in strategic importance during the second half of the nineteenth century. The long history of involvement in polar exploration by the RN, including the early scientific voyages of Edmund Halley (1656-1742) and Cook has been described in detail elsewhere (Berton, 1988; Coleman, 2006; Lewis-Jones, 2006). There had been a half-century gap since Ross commanded the most recent official RN (*Erebus* and *Terror,* 1839-43) expedition to the Antarctic. Subsequently Franklin became ice bound and perished with the same ships in his 1845-1848 attempt to locate and traverse the Northwest Passage. Of the numerous different expeditions sent to search for, or resupply Franklin's lost expedition "…slightly more than half the maritime and overland search expeditions, and all of the supply expeditions, were planned and executed by one authority -the Admiralty" (Gillies Ross, 2004). Headland states: "Owing to the consequences of this expedition, and the Crimean War (1845-56), British naval interest in polar exploration diminished until later in the 19$^{th}$ Century" (Headland, 2009, p. 169). George Strong Nares' (1831-1915) *Challenger* expedition of 1872-1876 circumnavigated the globe in high southern latitudes and crossed the Antarctic Circle, but it was a purely scientific voyage and was not intended to undertake Antarctic exploration. It was a RN expedition, but sponsored by the RS (Bryan, 2011, p.

117). It established oceanography as a discrete scientific discipline. Nares was recalled early, and left that expedition in Hong Kong to lead the (H.M.S.) *Discovery* (ex *Bloodhound*, an earlier vessel than S.S. *Discovery* of 1901) and *Alert* North Polar expedition of 1875-76, another purely navy enterprise (Headland, 2009, p. 201). With no naval conflicts during the second half of the nineteenth century the RN languished and lost form. In Markham's plea for the renewal of Antarctic exploration he stated "Antarctic exploration has hitherto been conducted by the Navy, and belongs to it by right of noble work well performed during more than a century" (Markham, 1898a, p. 1). When the *Discovery* expedition embarked it was a private concern and Markham billed himself as the "Managing Owner" in his capacity as President of the RGS, and the ship was registered as a yacht in his name (Bryan, 2011, p. 151). The majority of the officers and crew were lent to the expedition by the RN and remained on the payroll (Erskine, 1969). Naval involvement in exploration was not unique to Britain. A thorough description of a similar historic involvement by the American Navy in exploration, with a focus on Wilkes' United States Exploring Expedition to the Antarctic and Pacific regions (1838-42) is detailed by Littlehales (1899). Dumont d'Urville's expedition of 1837-1840 was a naval enterprise intended to bring cause for self-congratulation to the French Navy and render services to science (Rosenman, 1992, p. 2).

In the last decade of the nineteenth century Admiral Jackie Fisher (1841-1920) commenced a program of renewal for the Navy. His term was marked by changes in attitude, less time was devoted to ceremonial aspects and obsessive polishing, and more energy was put towards training with a renewed emphasis on speed, fighting efficiency and tactics as Fisher believed in peace though deterrence. Additionally there were numerous organisational changes in the navy and the culture of "entrenched hierarchy that smothered any spark of initiative" was dismantled gradually. Promotion according to merit rather than length of service became possible. Fisher's reform of the Navy as a world force culminated in construction of massive, steel hulled dreadnoughts with steam turbine power after he became First Sea Lord in 1904 (Snow, 2011). Sailing ships were already obsolete in the Navy in terms of speed, manoeuvrability and firepower and timber hulled sailing ships were an anachronism (Barnett, 2010). In terms of social status, the Navy was a respectable career, but it was, like the clergy, for the less wealthy (Tuchman, 1966, p. 13).

## 4.2 Scientific paradigms at the end of the Victorian era

The scientific activities of interest in this research emerged as legacies of RN exploratory and scientific voyages during the two centuries prior to 1900. Ship-based science as an adjunct to voyages of exploration was the normal model for the RN during times of peace when hydrographic survey was the most meaningful employment for vessels and their crew that were otherwise idle. Under Francis Beaufort's (1774-1857) leadership as Admiralty hydrographer from 1829, the incidence of surveying expeditions increased as never before, establishing the paradigm of the RN as leaders in exploration, science and survey. A key difference between the British expeditions and those of the French and American navies was the recruitment of scientific staff. The British Admiralty encouraged dual roles of surgeons and surgeon's assistants to act as naturalists and it was uncommon to have specialist scientific staff who were not members of the crew. In contrast (during the nineteenth century) the French and American navies commonly had specialist botanists, geologists and zoologists (Goodman, 2005, p. 9).

Some well-known examples of exploration are also the most significant scientifically. These include the voyages of Halley, whose research concerned terrestrial magnetism and the determination of longitude (HMS *Paramour*, 1698-99). The three famous voyages of Cook followed: firstly to observe the 1769 transit of Venus (HMB *Endeavour* 1768-71), secondly to search for the unknown southern continent (HMS *Resolution* and HMS *Adventure*, 1772-75) and finally to search for the North-West passage (HMS *Resolution* and HMS *Discovery*, 1776-80). Cook's high regard by the Victorian public is demonstrated by Ross's reference to him as "our great navigator" knowing that no further explanation was necessary, as all readers of the narrative would know to whom he referred (Ross, 1847, Volume I, p. 183). Ross took part in a privately funded voyage to the Arctic during which he undertook magnetic survey work in the region of the north magnetic pole serving under his uncle, John Ross (1777-1856) in the steam powered *Victory*. He was an obvious choice for the HMS *Erebus* and HMS *Terror* Antarctic campaign (Berton, 1988, p. 114) whose objective was to sail to the region of the south magnetic pole. The scientific harvest was great in the physical and natural sciences, and Hooker, assistant surgeon and botanist and Robert McCormick (1800-1890), surgeon and naturalist, carried out fieldwork that established their reputations as natural philosophers (Erskine, 2009, p. 27). There was a 30-year break from Antarctic exploration before Nares' HMS *Challenger* expedition (1872-76) but many commercial voyages touched on the Antarctic Circle in their search for whaling and sealing grounds in the nineteenth century. The Norwegian whaling voyage of Svend Foyn's (1809-1894) *Antarctic* for example, nudged into the Ross Sea and made a landing at Cape Adare in January 1895 (Borchgrevink, 1895).

### 4.2.1 Imperial contributions to scientific operations

The spread of the British Empire in the nineteenth century was vast. Without the Empire, access to the natural world beyond Britain's shores would have been very limited for naturalists (Endersby, 2008, p. 312). Wherever RN exploring expeditions travelled there were friendly ports for resupply and provision of support for scientific enterprises. Replacement of sailors who were unfit, who didn't fit in socially, were unenthusiastic or who had perished was another reason to visit ports that were part of the Empire, or were regularly visited by RN vessels. On the first Franklin Arctic expedition of 1819-1822 shelter, food, equipment, local knowledge and local manpower were all supplied by representatives of the Hudson's Bay

Company that controlled trading outposts in the Canadian Arctic. Strangely, for a RN expedition, this odyssey was mostly an overland trek in the interests of exploration and science. Physical observation instructions obliged Franklin to:

> Not neglect any opportunity of observing and noting down the dip and variation of the magnetic needle, and the intensity of the magnetic force; and should take particular notice of whether any, and what kind or degree of, influence the Aurora Borealis might appear to exert on the magnetic needle…
>
> (Franklin, 1823, p. 2)

These were sophisticated observations for an overland party on the move in the high Arctic. Further evidence of the role of Empire in expedition logistics and science is demonstrated by the local support provided to the expedition of Ross in Cape Town, en route to the Antarctic. The main building of the Cape Observatory was commenced in 1825 and functional by 1830, but it was not until Ross's visit in 1840 that the magnetic observatory was established. Ross was subsequently well received at Hobart, Van Diemen's Land (now Tasmania) by Franklin, who arranged convict labour to construct a magnetic observatory at "Rossbank" within the grounds of the current Governor's residence (Savours & McConnell, 1982). The scene is recorded by the artist Thomas Bock (1790-1855) who portrayed Captains Franklin, Ross and Crozier together amid the array of magnetic instruments in the rudimentary observatory (Image 1).

Image 1: *Rossbank Observatory, Hobarton* by Thomas Bock (1842). Captains Ross, Crozier and Franklin in foreground with observatory buildings in background and a selection of magnetic survey instruments on pedestals and tree stumps. Reproduced with permission of the Tasmanian Museum & Art Gallery, Hobart, Australia (AG241).

### 4.2.2 Scientific staffing on expeditions

Prior to the twentieth century it was normal for scientific work on RN expeditions to be performed by officers, and scientists who were wealthy gentleman. Science as a profession was barely coming into existence, as explained by Endersby: "…during the first few decades of Victoria's reign, British men of science still saw themselves as disinterested gentlemen, not as scientific tradesmen, much less as servants of centralised government, as were their French colleagues" (Endersby, 2008, p. 2). Throughout the eighteenth and nineteenth centuries science and scientists were adjuncts to voyages, not the rationale for them, except in the rarest cases. Edmund Halley's *Paramour* voyages (1698-99) were mounted in the cause of magnetic science. Halley, acting as commander and expedition leader had poor leadership qualities, and after this experience the RN never allowed a civilian to take command of one of their vessels (Fulford, Lee & Kitson, 2004, p. 162).

The best known example of the gentleman scientist was the natural philosopher Joseph Banks (1743-1820), who travelled with Cook to Tahiti for the transit of Venus of 1769 and beyond to New Zealand and Australia. Banks "focused his money and influence on turning the voyage into a grand scientific adventure-with stunning results" (Erskine, 2009, p. 17). Cook's subsequent *Resolution* and *Adventure* expedition (1772-1775) carried the civilian naturalists Johann Reinhold Forster (1729-1798) and his son, also Johann, but known as Georg (1754-1794) in place of Banks, after a famous falling-out between Banks and Cook. Forster was paid for this service and was not part of the ship's crew (Forster & Hoare, 1982, pp. 48-52). Ross's *Erebus* and *Terror* expedition was based on a program of inquiry into the physical sciences and, in line with normal practice, a naturalist was part of the crew. Hooker joined as assistant surgeon and botanist then later, as a fellow of the RS and through his membership of the Joint Committee that managed the affairs of the *Discovery* expedition, had the chance to influence the development of the scientific program for that expedition. In 1846 Captain Owen Stanley (1811-1850) of HMS *Rattlesnake* made preparations for a voyage of exploration and survey of northern Australia and New Guinea. He had a personal interest in science and was a fellow of the Royal Astronomical Society, the RGS and the RS (Goodman, 2005, p. 15). The naturalists on the expedition were John MacGillivray (1821-1867) and Thomas Huxley (1825-1895). MacGillivray was a (civilian) naturalist and Huxley was the assistant surgeon to the ship. Huxley and Hooker both had eminent post-voyage scientific careers and influenced the thinking of Darwin during development of his ideas about natural section.

The *Challenger* expedition of 1872-76 represented a turning point in RN scientific enterprises. Not only was it the first purely scientific expedition since Halley's *Paramour* (Conrad, 1999, p. 67), it was the first to have a scientific scholar as the director of a dedicated civilian scientific team of naturalists, a chemist and an artist. Thompson, the director and promoter of the expedition was a professor of natural history. A committee of the RS selected the six civilian scientists who worked with ships officers in the performance of scientific enquiry in physical oceanography. The navy considered that regular training of officers made them fit to perform the duties of deep sea sounding and the collection of water and sediment samples, as well as the routine meteorological, magnetic and navigational observations (Jones & Jones, 1992, p. 217). Steam propulsion facilitated probing the ocean depths at specified sampling points along latitudinal or longitudinal transects by allowing the ship to hold station. Detailed, serial measurement of deep ocean temperatures allowed latitudinal or longitudinal cross sections, or vertical profiles of oceanic basins. The expenditure on the expedition was recouped by the discovery of the phosphate deposits of Christmas Island by the oceanographer Murray (Jones & Jones, 1992, pp. 216-235). Later in life Murray was a strong supporter and advocate for Markham's Antarctic expedition, being one of the key delegates at the 1898 RS meeting where he spoke on the benefits of such an expedition.

These men operated within the paradigm of RN sponsored science on exploratory voyages in the eighteenth and nineteenth centuries. Although science was often incidental and scientific activities relied on the interest and goodwill of the commanding officer, many of these well-salted natural philosophers (Darwin, Huxley, Hooker and MacGillivray) proved their scientific credentials and became influential fellows of the RS and other august bodies. Their examples set the model for polar frontier science at the turn of the twentieth century.

### 4.2.3 Metropolitan vs. Colonial (Centre and periphery) science

Antarctic science around 1900 can be described in terms of the model proposed by Basalla describing the diffusion of western science introduced at Section 3.7. His model represents three phases in the evolution of scientific practice at the periphery (away from Western Europe) and the progress towards independent scientific cultures in remote locations. It describes how western science was introduced to Eastern Europe, North and South America, India, Australia, China, Japan and Africa. Aside from the element of nationhood, the model fits the evolution of Antarctic science. Phase 1 is characterised by:

> the European who visits the new land, surveys and collects its flora and fauna, studies its physical features, and then takes his work back to Europe. Botany, zoology, and geology predominate during this phase, but astronomy, geophysics, and a cluster of geographical sciences-topography, cartography, hydrography, meteorology-sometimes rival them in importance.
>
> (Basalla, 1967)

At that stage science is an extension of exploration and assessment of natural resources, and the periphery serves as a source of material for the further development of European scientific theory (Inkster, 1985). Phase 2 sees the emergence of local scientific traditions and engagement in scientific practice by colonial scientists. The range of scientific activity increases to match that of the nation supporting the activity. The final stage is characterised by the development of an independent scientific tradition. The practitioner's orientation shifts from looking outwards to external scientific cultures towards one bounded by the "country" in which he or she works.

Basalla acknowledges the model must be modified to meet specific situations. The Antarctic example diverges from the model, as no single national identity has evolved, but a coherent community with a distinct scientific intellectual tradition has taken its place. Indicators of the highest stage include social prestige, state funding, science education, the foundation of scientific organisations and the establishment of scientific journals (MacLeod, 1982) and the current state of Antarctic science fits these characteristics. MacLeod refined Basalla's definitions of metropolitan science and colonial science. The former is "a way of doing science, based on learned societies, small groups of cultivators, certain conventions of discourse, and certain theoretical priorities set in eighteenth-century Western Europe." In contrast, "Colonial" science was carried out by collectors working on problems set by *savants* in Europe: it was "low" science and was identified with fact gathering. The work of theoretical synthesis took place elsewhere (MacLeod, 1982).

Hooker left a number of legacies germane to the *Discovery* expedition and its scientific program. He continued the entrenchment of the metropolis / periphery model of scientific practice by his carefully controlled relationship with the botanical collectors around the world such as Ronald Gunn (1808-1881) in Van Diemen's Land and William Colenso (1811-1899) in New Zealand, and his discouragement of their efforts to undertake taxonomic analysis or publication of findings. These intellectual activities were performed at Kew on the specimens they had identified as significant and had collected, preserved and sent to him (Endersby, 2009, p. 75). Basalla and MacLeod's model provides context to the performance of science on the *Discovery* discussed in the following chapters.

#### 4.2.4 Scientific thinking and the performance of science in 1900

Science was not a professional activity in 1800 but it emerged as such over the next century. In America in 1802, for example, there were only twenty-one individuals earning a livelihood as a scientist and, in a catalogue of thirteen hundred books printed in the US, only about twenty were considered works of science, and most were textbooks rather than theoretical works. The publication of journals is a proxy indicating the expansion of science prior to 1900. The first two scientific journals, one of which was the *Philosophical Transactions of the Royal Society* were first published in 1665. In 1700 there were about thirty scientific and medical journals in regular production. By 1900 this number had ballooned to around 2000 (Shamos, 1995, pp. 36-37). Scientific practice has not always been considered a virtuous pastime. Endersby's analysis of the Imperial scientific tradition opens with:

> …during the early decades of the nineteenth century, being paid to do science put one, not among the elite, but in the same category as Banks's servants, the people he paid

> to collect, illustrate, and curate for him. The association between receiving payment and low social standing lingered well into the second half of the century.
>
> (Endersby, 2008, p. 2-3)

Clear definitions of what constitutes "science" are elusive. Key elements of scientific literacy include: bodies of useful or practical knowledge about the universe, methods of inquiry, searches for order in nature or first principles and sufficient understanding to explain and make predictions about natural phenomena (Shamos, 1995, p. 47). In terms of process:

> Science is not merely a matter of accurate and detailed descriptions of things, or of extending our senses through the use of scientific instruments….These are merely steps –important ones but nevertheless only a means to a much larger objective: the design of conceptual schemes, models and theories that serve to account for major segments of our experience with nature, and ultimately form the bases for all explanation in science.
>
> (Shamos, 1995, p. 46)

Nineteenth century magnetic science in Britain was dominated by the efforts of Major Edward Sabine (1788-1883) whose approach was similar to that of Halley, following a process of gathering data then looking for patterns and meaning within it:

> Global certainty rested on the accumulation of data. Halley, for instance, was uncertain about how magnetic declination[2] operated but was confident that once sufficient observations had been accumulated it would be possible to attain certainties such as the determination of longitude by magnetic means. Getting the data became the priority.
>
> (Fulford et al, 2004, p. 154)

Sabine was obsessed with data gathering, and used the resources of Empire to acquire data from colonial outposts. Sabine published many *Contributions to terrestrial magnetism* in the *Philosophical Transactions of the Royal Society* that were mostly summaries of the trends in raw data acquired from observatories and vessels. It's true that a long term, sustained

[2] The magnetic elements of declination, dip, intensity, deviation and their synonyms are defined in section 4.3.1

sampling effort was required in terrestrial magnetic studies (as with meteorology) to yield meaningful results, but Sabine's publications did not progress the development of theory. This analysis was criticised by the astronomer John Herschel (1792-1871) as "chartism" in a scathing attack during his Presidential address to the British Association for the Advancement of Science in 1845, especially with regard to analysis of the outputs of Ross's *Erebus* and *Terror* expedition (Endersby, 2008, p. 235). This is at odds with Sabine's speech to the seventh meeting of the association, in 1837, where he argued for the expedition to carry out experiments to test the popular hypothesis of four magnetic poles. Here he stated that previous observations had been made without reference to theory (Cawood, 1979). It was exactly the results of this expedition (Ross's *Erebus* and *Terror*) that Herschel was criticising.

Humboldt, the German polymath, whose travels to South America between 1799 and 1804 had inspired Darwin to join the *Beagle* for its epic journey, was another significant influence on Victorian scientific traditions. Humboldt's journey included magnetic observations and ensured "magnetism would be on the agenda for British arctic explorations of the early 19$^{th}$ Century" (Lambert, 2009, p. 8). Humboldt joined the magnetic lobby's agitation in Britain for Ross's expedition and it's associated network of observatories. His influence in Britain shifted the focus of magnetic research away from the north magnetic pole and introduced a broader approach: "Consideration of the magnetic field as a cosmic phenomenon helped to broaden the subject and break down the barriers which the narrower interests of the Navy might have imposed" (Cawood, 1979).

Extensive cooperative magnetic observing was promoted by the German physicists and magnetic experts Gauss and Weber with the establishment of the *Göttingen magnetische Verein* in 1834. They applied a more abstract mathematical approach to the science than Humboldt's cosmical tradition, which was underpinned by an astronomical approach to terrestrial magnetism, reliant on concepts of apparently interrelated phenomena such as volcanic activity, atmospheric electricity and heat of the earth (Cawood, 1979).

There was a clear hierarchy within scientific disciplines in the nineteenth century and the physical sciences were perceived as superior. “In the early decades of the nineteenth century, botany was looked down on by the practitioners of more prestigious and demanding sciences, like physics and astronomy” (Endersby, 2009. p. 77). “In the years following the appearance of *The Origin,* [Darwin’s *Origin of Species*] physical geography, in common with other earth and life sciences, was transformed” (Stoddart, 1975). The publication of T. H. Huxley’s *Physiography* in 1877 transformed popular thinking about geography and laid the foundation for the natural sciences to become incorporated into common understanding and the school curriculum in Britain. Huxley was a highly influential scientific thinker and his view of science was based on three levels: observational science (the collection of facts), classificatory science (arrangement of facts) and inductive science (facts reasoned and laws deduced) (Stoddart, 1975). Victorian science was mostly descriptive, not predictive and prior to the publication of Huxley’s *Physiography*, physics, chemistry, botany and zoology went untaught in British schools. The geographer (and polar specialist) Hugh Robert Mill (1861-1951) included geology, astronomy, geography, meteorology, biology and chemistry within Huxley’s new discipline. James Dana (1813-1895), geologist aboard Wilkes’ United States Exploring Expedition (1838-42), included magnetism as one element of the natural world in his version of physiography published in his influential *Manual of Geology* (Stoddart, 1975). Physiography as a discipline disappeared by the turn of the twentieth century, as it was too broad in its own right. The scientific disciplines mentioned above (with the addition of geomorphology that was spawned directly from physiography) stood alone.

Endersby sums up: “The transformation of Britain’s men of science into modern scientists had been a slow, uneven process that had taken most of the nineteenth century, and whose course had varied according to discipline and institutional setting” (2008, p. 311).
A feature of late nineteenth century science was its release from obligations to either seek a solution to a practical problem or to illustrate a biblical text. Theoretical science was now practiced as an intellectual pursuit and applied science was considered a lower form of intellectual activity. Prior to Darwin’s paradigm shifting thoughts on evolution and natural selection, science education had been confined to religious and utilitarian aims, but publication of his *Origin of Species* opened the door for free thinking (Shamos, 1995, pp. 39-40).

The scientists on the *Discovery* were embarking at a time of rapid development in scientific disciplines and their practice. The intellectual legacy they worked within was overwhelmingly dominated by “inductive” methods, in which theory is derived from observations. Hypothetico-deductive methods that generated theory by first developing hypotheses, then designing experiments to test them, were outside their intellectual landscape.

### 4.2.5 Cooperative magnetic observing networks

The idea of cooperative scientific observing at numerous locations around the globe and by a mix of nations was entrenched by 1900. Humboldt left Paris in 1827 after a stay of seventeen years, during which he wrote the findings of his South American trip, then in 1829 he took part in an expedition to Siberia and “managed to persuade the Emperor, Nicolaus I, to establish a string of magnetic observatories across European and Asiatic Russia” (Cawood, 1977, p. 584). He then returned to Germany to participate in the establishment of Gauss and Weber’s *Göttingen magnetische Verein*. On Sabine’s prompting, Humboldt wrote to the RS in 1836 seeking to join the combined magnetic observing networks of France, Russia and

Germany into a global network. There was no action on this matter until Herschel returned from Cape Town in 1838 and brought his influence to bear. Arrangements for a global network of coordinated magnetic observatories were in place in time for Ross's *Erebus* and *Terror* expedition (Cawood, 1977, pp. 583-585). A further example of global data collecting in the physical sciences is the first International Polar Year of 1882-83. The Austrian, Karl Weyprecht (1838-1881), at a meeting of German naturalists and physicists in Graz in 1875 proposed the formation of a ring of scientific stations around the Arctic Circle, where synchronous weather, terrestrial magnetism, and other geophysical observations would be made over the span of a year. This scheme led to the first International Polar Year during which scientists from ten European nations cooperated with the US, who operated fourteen stations. French and German bases added southern hemisphere data from Cape Horn and South Georgia respectively (Belanger, 2006, pp. 10-11). Cooperative global observing networks in the physical sciences were an element of the Victorian scientific tradition that informed the development of the magnetic science program for the *Discovery* and *Gauss* expeditions.

## 4.3 Terrestrial magnetic science in 1900

### 4.3.1 The elements of terrestrial magnetism

Research into terrestrial magnetism, also known as geomagnetism, remained an observational scientific activity at the end of the Victorian era. The phenomena could be described mathematically but the causes of the observable phenomena remained a mystery. Secular, seasonal and diurnal changes in the measurable elements were recognised, but not understood. A leap forward in comprehension of the phenomenon was anticipated from the scheme of synchronous observations planned during the *Discovery* and *Gauss* expeditions. This section describes some aspects of development of the science of geomagnetic research especially during the Victorian era, and discusses its place in the art of traditional navigation and the linkage to selected high latitude expeditions.

There were two stimuli for magnetic research: commercial and intellectual. The mercantile products of scientific magnetic research at sea were charts showing magnetic features that assisted navigators in the days of sail. Secondly, scientific intellectual inquiry was informed by better determination of the location of the magnetic pole, data to assist solving the causes of terrestrial magnetism, confirmation of the global synchronicity of secular and diurnal changes in magnetic elements and finally, the synchronicity of magnetic disturbances and their relationship to magnetic storms on the sun and the appearance of auroras. With a few exceptions, systematic observations had been confined to the northern hemisphere prior to 1900 and the first and only voyages to the proximity of the south magnetic pole were those of Ross, Wilkes and d'Urville around 1840. No systematic long term magnetic observing had been undertaken on those voyages so Antarctica was a blank sheet in terms of research into magnetism.

There are three elements of terrestrial magnetism of interest to physicists that could be determined using the instruments available in 1900. These are declination, dip and intensity. Declination is the angular difference between true (or geographic) north and the magnetic meridian at any place on the surface of the globe. Physicists use the symbol "D" for this angle between "H" (magnetic north) and "Y" (true north) (Jonkers, 2003, p. 25). Declination is also referred to as "variation" by mariners. This is the simplest measure of a locality's ambient magnetic field and instruments have been available to make determination of variation since before the time of Halley's *Paramour* voyages. Charts showing lines of equal magnetic variation, isogonic lines, indicate the magnetic meridian at any place on the chart. The isogons converge toward the magnetic poles and this type of chart was of some use in practical navigation.

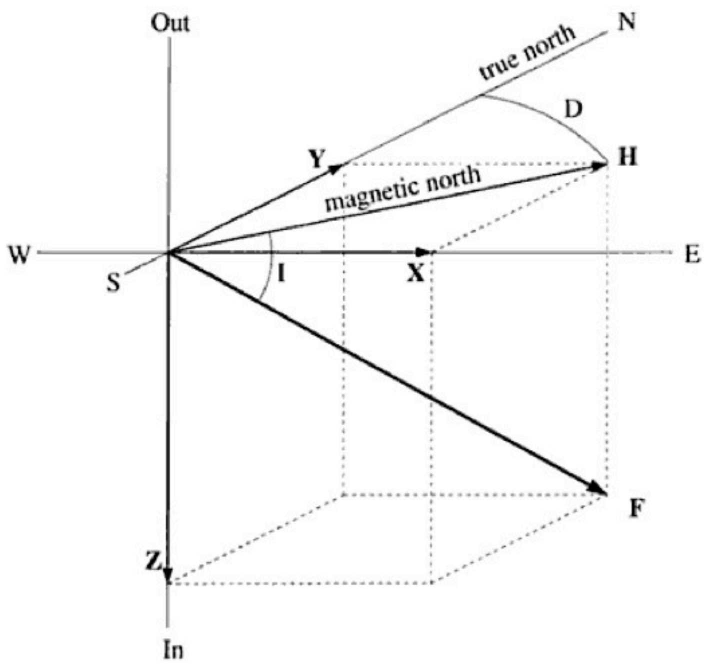


Figure 2: Elements of terrestrial magnetism reproduced from Jonkers (2003, p. 25), with author's permission.

As the source attracting the magnetised needle appears to be within the earth, not on its surface, a measure known as magnetic dip is used to describe the angle that the magnetised needle makes with the horizontal when free to move vertically and is aligned along the local magnetic meridian (H). This angle is also referred to as inclination and physicists define it as "I", being the vertical angle between "H" (magnetic north) and "F" (the full magnetic vector). Charts of lines of equal magnetic dip are called isoclinal lines and the magnetic equator is found along the line of zero dip. The magnetic pole is the locality where the dip is 90° causing the dip needle to point directly downward. The notional points known as the Geomagnetic Poles are points that best fit an antipodal magnetic dipole, a theoretical arrangement only that is of no utility in research into terrestrial magnetism (Mawer, 2006, p. 157).

"Intensity" represents the strength of the magnetic field of the earth. The symbol "Z" is used to represent the radial force of the field relative to its source. Total magnetic intensity "F" may be calculated for any locality and time then expressed as a single number by combining the vectors of horizontal and vertical intensity. Although determination of the direction of the vectors was possible, determination of the absolute field strength was not possible until the invention of the magnetometer by Gauss in 1832 (Jonkers, 2003, p. 26). Previously, relative field strength in the horizontal plane could be determined by the rate of oscillation of a compass needle but comparison was rarely valid as each needle had a unique magnetic signature.

Deviation is a mariner’s term to describe the measure of the influence on ships compasses caused by ferrous materials in the ship’s fabric or it’s cargo. Hard iron in ships is permanently magnetised and soft iron can vary in its magnetic polarity and strength over time. Deviation changes according to the ship’s direction and the heeling angle. “Swinging” the ship is the process that determines the values of compensation for deviation required, according to direction of travel. Mariners also refer to “compass error”, an angular value that combines the variation and the deviation to provide an angle that may be applied by the helmsman to stay on a true course.

### 4.3.2 The development of terrestrial magnetic theory and practice

The eighteenth century commenced an age of magnetic data collection promoted by the expansion of more numerous and more sustained seafaring and improvements in the technology and sophistication of instruments. This followed a period of numerous theoretical, but mostly unsubstantiated postulates about the nature and causes of terrestrial magnetism developed during the seventeenth century (Jonkers, 2003, p. 126). There were four phases of development of geomagnetic theory concepts. The first theory consists of a static axial dipole interpreting the earth as a magnet with the magnetic poles opposite and fixed at the geographic poles.  The next phase was a tilted, but still static dipole. The third phase has a tilted dipole that is no longer static, but precessing. The fourth stage recognises that the magnetic poles are not diametrically opposed as in the dipole models, but independent, and dynamic. The fourth represents reality. Many theories along these lines replaced a cosmological view that had the magnetic poles were the same as the celestial poles (2003, pp. 33-38). A brief synopsis of the significant milestones in magnetic research and development of theory from earliest records follows, and a more detailed, annotated chronology of theory and research into terrestrial magnetism is found at Appendix II.

Between 1799 and 1804 Humboldt surveyed magnetism in South America at more than one hundred locations and determined that magnetic intensity increased with increasing latitude on land, as well as at sea. He used a site in the Peruvian Andes as his reference station as it was on the magnetic equator (McConnell, 2005, p. 353). During the same years Matthew Flinders (1774-1814) surveyed the coast of New Holland (Australia) and took thousands of observations including details of compass bearings, date, time, ship's heading, magnetic dip and geographic latitude and longitude. He noticed that the iron on board ship caused deviation and showed that swinging the ship around the points of the compass and recording the apparent declination on each heading could allow compensation to be made at sea (Gurney, 2004, p. 153; Mawer, 2006, p. 12). John Churchman (1753-1805) had initially proposed this solution in 1796 (Jonkers, 2003, p. 169). On his return to England (after incarceration by the French) in 1812, Flinders proposed the Admiralty carry out a series of experiments related to deviation after which he devised a solution known as the "Flinders bar", which was composed of soft iron and placed vertically and below the ship's compass in the binnacle (Gurney, 2004, p. 171).

After 1818 the British Admiralty sent numerous expeditions on the quest for the North-west passage, affording opportunities for magnetic science as an adjunct to exploration. Theoretical background progressed when Norwegian Christopher Hansteen (1784-1873) published *Magnetismus der Erde* in 1819, postulating that there were two principal magnetic axes, and therefore four principal points of convergence of the direction of the magnetic needle, all constantly moving. Sabine published data in 1825 indicating its "incompatibility with the hypothesis of a single magnetic axis." Hansteen further developed methods of determination of total intensity using values from the horizontal component and the inclination rather than the old dip needle method (Turner 2010, p. 108). Between 1825 and 1835 Humboldts comprehensive observing network took simultaneous observations in France and Russia, Sitka (Alaska) and Peking. On six "term days" each year simultaneous observations were made every five minutes for twenty-four hours (Mawer, 2006, p. 11).

Ross established a camp at the locality of the North Magnetic Pole on the Boothia Peninsula in 1831 using a magnetometer and dip circle to determine its location (Mawer, 2006, p. 3-4). The following year Gauss improved technique with:

> a method for measuring intensity absolutely, in units of mass, distance and time, rather than by comparison between the number of oscillations of the same needle in different locations. The observational technique, devised with his collaborator, Wilhelm Weber, involved counting oscillations, as before, then using the dipping needle to deflect the compass needle.
>
> (Mawer, 2006, p. 12)

Weber and Gauss opened the observatory in Göttingen that became responsible for coordinating term days and the collection and publication of observations for the Göttingen Magnetic Union collaboration after 1834 (Mawer, 2006, p. 12). A turning point in practical application of theory occurred when George Airy, Astronomer Royal (1801-1892) used magnets to successfully correct compass deviation on the *Rainbow* after swinging the ship in the basin at the Deptford victualling yards at Greenwich. This was followed by his engagement to carry out the same procedure for the new ship *Ironsides*, the first iron-hulled sailing ship (Gurney 2004, pp. 200-203). In 1838, the magnetic observatory was added to Greenwich Observatory by Airy who realised the practical work of the observatory up to that time was mainly chronometer rating (Gurney, 2004, p. 197). On the theoretical side, Gauss used data collected by Sabine to determine mathematical formulae to describe earth magnetism and predicted the magnetic poles would be at 77° 84' N, 296° 30' E and 77° 8' S, 116° 30' E. Published as *Allgemeine Theorie des Erdmagnetismus,* it also postulated (correctly) that nearly all normal magnetic force came from the earth but daily, seasonal and irregular disturbances were probably cosmic in origin (Turner 2010, pp. 122-123; McConnell, 2005, p. 353). The intense activity in research in terrestrial magnetism was continued by the "Magnetic Crusade", in which three major national expeditions touched on Antarctica in search of the south magnetic pole (Cawood, 1979). They were Ross's (*Erebus* and *Terror, 1839-43*), d'Urville's (*Astrolabe* and *Zelee*, 1837-1840) and Wilkes' (U.S. Exploring Expedition consisting of *Vincennes, Peacock, Porpoise, Sea Gull, Flying Fish* and *Relief*, 1838-42). Ross determined south magnetic pole to be located at 75° 5' S, 154° 8' E and published charts of variation, dip and intensity (McConnell, 2005, pp. 354-5).

Development of theory continued and Sabine showed in 1851, after mining his mass of magnetic data, that the intensity of geomagnetic disturbances varies in concert with the eleven-year periodicity of sunspots confirming the findings of Heinrich Schwabe (1789-1875) seven years earlier. Awareness was growing that frequency of magnetic storms also followed the sun spot cycle (Kivelson & Russell, 1995, p. 6). Richard Carrington (1826-1875), while sketching sunspots in 1859, observed a great flare of white light on the sun. Kew observatory had been running continuous magnetographs since the previous year and at that moment they recorded a disturbance of the magnetic field then, eighteen hours later, one of the strongest magnetic storms ever recorded broke out. Auroras were seen at lower latitudes than previous records showed, and the speed of the solar wind was determined to be over 2,300 km/s (Kivelson & Russell, 1995, pp. 6-7).

Instruments for navigation were also becoming more sophisticated and reliable. Sir William Thomson, later known as Lord Kelvin (1824-1907) developed the compass binnacle in 1876. It incorporated soft iron spheres whose location could be adjusted and a Flinders bar installed below the compass. It also incorporated a dry pivot compass of Thompson's own design. This binnacle pattern came into popular use (Gurney 2004, pp. 240-242).

The first journal dedicated to reporting studies in the discipline (*Terrestrial Magnetism*) came into existence in 1896 under the editorship of the American, Bauer, who had a doctorate on the secular variation of geomagnetism. Soon after, its scope was expanded and it was renamed *Terrestrial Magnetism and Atmospheric Electricity* (McConnell, 2005, p. 357). The (British) National Physical Laboratory was established in January 1900 as a separate entity from its parent institution, Kew Observatory and in 1904 Bauer, across the Atlantic, was appointed director of the newly formed Department of Terrestrial Magnetism at the Carnegie Institution in Washington, D.C. (McConnell, 2005, p. 357). The quest for the south magnetic pole closed initially in January 1909 when Mawson, David and Alastair MacKay (1878-1914) reached the locality of the southern magnetic pole in the Antarctic at 72° 25' S, 155° 16' E during Shackleton's *Nimrod* expedition. The link between perturbations in the magnetic field (also referred to as "disturbances" or "magnetic storms"), auroras and space weather were also being investigated in the early twentieth century by the Norwegian physicist, Kristian Birkeland (1867-1917) (Jago, 2001).

### 4.3.3 Sir James Clark Ross and Sir John Franklin

Ross and Franklin were giants in the arena of polar magnetic studies in the nineteenth century and their work deserves mention as it related directly to the research aboard *Discovery*. Ross was first to the north magnetic pole, located at the time on the Boothia Peninsula (70° 05' N., 96° 46' W.), where he made magnetic observations. On arriving in June 1831 he wrote:

> It almost seemed as if we had accomplished everything we had come so far to see and to do; as if our voyage and all its labours were at an end and that nothing now remained for us but to return home and be happy for the rest of our days.
>
> (Savours, 1962)

Ross was then selected through Sabine's influence with the admiralty to take the *Erebus* and *Terror* expedition to attempt to sail to the South Magnetic Pole. This expedition was dispatched at a time when cooperation in magnetic science research was balanced against scientific rivalry (Cawood, 1979). Ross's introduction to the narrative of the voyage is an important document for the student of the history of research into terrestrial magnetism as it touches on many of the success factors of voyages of scientific exploration. It includes the justifications for the expedition, the institutional support and how governmental support was requested and granted, the state of theoretical and practical knowledge in the discipline at the time, an overview of the protocols for observing and finally, the Admiralty instructions to Ross (1847, pp. xxii-xxviii). Scott's introduction to the narrative of the *Discovery* expedition provides a short piece referring to the magnetic research of Ross which erroneously implies that it was more about navigation than science: "its practical importance in connection with the navigation of ships was now fully realised" (Scott, 1905b, p. 15). Ross makes it clear that his expedition was founded on pure scientific research with the intention of gathering data on which to build theory. He acknowledges that the only observations likely to be of any utility to navigators are those of variation (declination) but he lists the numerous additional elements of the scientific inquiry (Ross, 1847, p. x). In addition to his post as a RN officer, Ross was a scientist who demonstrated his understanding of the theoretical elements of the scientific work at hand.

Ross's expedition was the product of a meeting of the British Association for the Advancement of Science (BAAS) in August 1838 at which Sabine spoke to the desirability of expanded research into terrestrial magnetism. A committee of scientific leaders formed with the intention of approaching the government to start an expedition. The objectives included extending the Göttingen Union's network of magnetic observatories to British dominions for hourly magnetic measurements and more frequent observations on selected term days. The committee recommended a naval expedition to high southern latitudes especially for declination and intensity measurements, and especially in the longitudes between New Holland and Cape Horn. Results were to be sent for compilation to Professor Humphrey Lloyd (1800-1881) in Dublin, the inventor of Lloyd's needles for measuring magnetic force. On receipt of the British Association's recommendations the government referred it to the RS (as advisors to the government on all scientific matters), who agreed with the proposed scheme (Ross, 1847, pp. i-vii).

The RS then developed their own report that provided background and guidance for the magnetic research on the expedition. It opens with a statement of purpose: "…completing our knowledge of the actual state of the magnetic phenomena, and furnishing accurate data for the construction and verification of theoretical systems." (Ross, 1847, p. viii). Some theoretical background follows, including the following key points that summarise the state of knowledge of terrestrial magnetism at the time:

- A magnetic cycle of several centuries may exist based on unknown internal movements or relations
- A periodic effect of the sun may be related to heating and cooling
- Auroras affect the compass needle
- The existence of minute and irregular movements of the needle
- Laws of terrestrial magnetism are not so simple as to allow a simple summary and the gist of the inquiry is deep and depends on complex relations
- Temporary changes are observed across the globe simultaneously
- Our knowledge of the actual and past state of the dip over the face of the earth's surface is lamentably deficient
- Dip can now be observed with considerable approximation at sea
- Intensity can be determined with exactness and this branch of magnetic knowledge has made rapid progress
- In order to provide precise descriptions of any observing station all three elements (declination, dip and intensity) must be recorded
- Declination is the only element of any practical use to navigators

- It is now known that all three magnetic elements are in a constant state of fluctuation

(Ross, 1847, pp. viii-x)

Ross continues by stating the rationale for the investigation:

- Thorough analysis of progressive and periodic changes is only possible by collecting sufficient data to allow elimination of transitory changes
- Secular magnetic changes cannot be concluded from a comparatively short series of observations
- Discordances between different magnetic observers may be due to transitory fluctuations, not observer (or presumably instrumental) errors
- A theory of transitory changes is of prime interest and should be found to contribute to general theories of terrestrial magnetism

(Ross, 1847, pp. xi-xii)

He continued with notes about the desired outcomes of government support that included the establishment of several observing stations with funding for staffing and instruments. The stations were to make observations of declination, dip and intensity using magnetometers hourly for three years and every five minutes over the twenty-four hour period of select term days and measurements were to be absolute, not relative, allowing easy compilation of data. On the assumption that the plea for a naval Antarctic expedition was successful, the observations at fixed stations (proposed for Canada, St Helens, Cape Town, Van Diemen's Land and Ceylon or Madeira) should be arranged through correspondence with the commander of the expedition (Ross, 1847, pp. xii-xv).

The grounds for the RS belief in the value of the expedition and scheme of observing are as follows:

- Great and notorious deficiencies exist in our knowledge of the curves of the variation lines generally, and especially in the Antarctic
- The true position of the south magnetic pole or poles can scarcely be determined with current data
- Knowledge of dip is completely deficient in these regions. Observations at sea and on the ice would be especially valuable

- There is little data on intensity lines and there is good reason to believe in the existence and accessibility of two points of maximum intensity in the southern, as in the northern hemisphere
- That correct knowledge of the courses of these lines, especially where they approach their respective poles, is to be regarded as a first and, indeed, indispensible preliminary step to the construction of a rigorous and complete theory of terrestrial magnetism.
- The importance of aligning observations with the fixed stations and the necessity for quality data are re-iterated here as these localities "…are unlikely to be revisited for any purpose, except those connected with scientific inquiries."

(Ross, 1847, pp. xv-xvi)

The RS Council resolutions that follow (Ross, 1847, p. xxvii) urged that the above report be approved, that the Council recommended to the government that the expedition should proceed, that fixed observatories be established and that a deputation was to be made to Lord Melbourne requesting adoption of all the proposals. After some detail of the vessels and their provisioning, Ross's introduction closes with the Admiralty's official instructions to him as commander.

After the return of the expeditions of Ross, Wilkes and d'Urville there were no further Antarctic expeditions concentrating on the physical sciences until the international campaign of the early 1900's. Franklin, who had been governor of Van Diemen's Land and had assisted Ross establish the magnetic observatory there, was a magnetic scientist himself. Franklin had been a midshipman on Matthew Flinders' *Investigator* voyage of 1801 and it's probable that Franklin's scientific interest in terrestrial magnetism was piqued by Flinders' own preoccupation (Erskine, 2009, p. 19). He was selected to lead the North-West passage expedition (*Erebus* and *Terror*, 1845) from which no one returned. His importance in the historical context of magnetic studies is related by Lambert:

> Arctic and then Antarctic naval commanders were left in no doubt that magnetic studies were scientifically the most important part of their mandate. Franklin had been at the

> heart of the magnetic crusade from the outset. He took command in 1845 because he had impeccable credentials, extensive arctic experience, proven leadership and above all because he was a first rate magnetic scientist.
>
> (Lambert, 2009, p. 61)

After the loss of the Franklin expedition there were numerous search and relief missions to the Arctic, but none with a scientific program that took priority over exploration.

## 4.4 Getting started: Patronage, institutional support and finance

Institutional prestige, personal patronage and funding are bound together in the case of the *Discovery*, as they were for all expeditions of its era. Funding and support for expeditions has always presented a challenge, but Markham showed his mettle by using his personal connections with the wealthy, management of the will of committees and, to some extent, management of the will of the government of the time. Markham also called in favours from acquaintances to speak on behalf of the expedition when it was expedient.

The funding was ultimately abundant, allowing it to follow the RN Arctic traditions of the nineteenth century and become "…cumbersome, overmanned and inefficient" (Markham & Holland, 1986, p. xxiii). In this case there were five prospective sources of funds and support. The prime source was the government, in the form of direct grants or through naval support. Another significant source was institutional grants, especially from the RGS. Philanthropy was the third in the suite of financial sources. Subscriptions circulated through the membership of institutions like the RS and RGS was an additional way to glean funds, but from sympathetic and not necessarily wealthy individuals. The last source was through direct public appeals circulated in newspapers. Corporate sponsorship was a minor source of support that generally came in the form of gifts of equipment of consumables such as food and coal.

Markham's personal notes track the chronology of fundraising and sponsorship efforts described here (Markham, n.d.b). The campaign opened at the 27 November 1893 RGS meeting where Murray delivered his paper on the *Renewal of Antarctic Exploration* (Murray, 1894). After the 6th International Geographic Congress in July 1895 Markham wrote to the George Goschen (1831-1907), First Lord of the Admiralty in November, proposing an all RN expedition. The secretary to the Admiralty replied promptly offering only the loan of instruments, and stating that, although it would take an interest in the expedition it could not lend officers. During 1896 Markham sought approval for the expedition from the influential RGS expedition committee, but it was denied, then, in his Anniversary Address to the RGS for Queen Victoria's Diamond Jubilee he argued that Antarctic work has always been undertaken by the government and is of great value to the training and readiness of the navy during peacetime (Markham, 1897). In April 1897 the Council of the RGS agreed to allow Markham to appeal for funds and opened the subscription list with a grant of £5,000 (Huxley, 1977, p. 25). At the end of that year Markham was still struggling to get momentum with funding so he invited the RS to join the enterprise. He reflected: "It was a fatal error, but I did so under the impression that the great name of the Royal Society would bring in funds" (Markham & Holland, 1986, p. 8). In October 1897 Markham wrote to Lord Salisbury (Prime Minister) asking for the expedition to be government sponsored and financed but on 9 June following (1898) there was a note of refusal but, undeterred, on 12 June Markham compiled a list of prospective ships available in Norway or that had seen polar service. The pamphlet, *Antarctic Exploration: A Plea for a National Expedition* was published by the RGS (Markham, 1898a) and private letters and appeals to fellows and members were circulated. Markham tried to snare funding from Australian premiers who were visiting Britain and secured a promise of £1000 from the Victorian Government (Yelverton, 2000, p. 9). After a February 1898 meeting of the Joint Committee of representatives from the RGS and the RS

(13 from each) that had been established to oversee the expedition, a small sub-committee was formed to arrange an application to the Government for a grant. In May 1898 the final rejection for an exclusive RN expedition was received from Goschen, so Markham set about reconfiguring it as a private, RGS enterprise. The publisher Alfred Harmsworth (1865-1922) promised another £5,000 (Mill, 1905, p. 408) and by the year's end £14,000 had been raised. Markham recorded that "he kept writing letters to rich people" (Markham & Holland, 1986, p. 9) and this strategy was successful, as he received an offer of £25,000 from the industrialist Llewellyn Longstaff (1841-1918). Once the funding had momentum and the credibility of the enterprise had been established, the Prince of Wales agreed to become patron of the expedition, lending his name in support of the fundraising effort. In earlier times "The science of geography was consistently funded by the princes and kings of Europe" (Sorrenson, 1996) but neither Queen Victoria nor her son (the Prince of Wales, later King Edward VII) assisted financially. In April 1899 Markham again appealed for government support with a letter "signed by some of the leaders of British science, headed by Lord Lister (1827-1912), president of the RS, and more than forty others ranging from the Astronomer Royal to university vice-chancellors" (Yelverton, 2000, p. 11). This paved the way for Markham's June 1899 deputation to Lord Balfour (1848-1930) who was acting on behalf of the Chancellor. He had a personal interest in science and read incessantly: "a book on science was propped open on the mantelpiece while he dressed." He also enjoyed mixing with scientists: "When visiting his sister, Lady Rayleigh, and asked by her what he would like in the way of entertainment, he replied 'Oh something amusing; get some people from Cambridge to talk science' " (Tuchman, 1966, p. 53). Balfour was sympathetic, and a commitment was made of £45,000, based on his belief that the science would reap rewards. Longstaff held the same expectation. The involvement of the RS had been crucial in persuading Balfour's cabinet to underwrite the venture (Baughman, 1999, p. 21). The RGS

then provided a further £3,000 to bring the donations up to the matching £45,000 of private funds required to meet the provision of the government grant. The final total of funds raised was £93,000, very close to the estimate of £95,000 for three (austral summer) seasons of exploration with a single ship, (Yelverton, 2000, p. 420) but short of Markham's higher target of £100,000 (Baughman, 1999, p. 18).

After allowance for construction of the vessel, £25,000 had been put aside for wages and voyage expenses (Savours, 1992, p. 25). The RN exploration model was to send ships in pairs to polar regions to ensure a line of retreat was available in case of misadventure (James Clark Ross *Erebus* and *Terror,* Nares' *Discovery* and *Alert,* Cook's *Resolution* and *Adventure* for example) but Markham's campaign was established as a "one ship" expedition. Markham probably always intended the acquisition of a second ship as he hastily commenced fundraising for the relief expedition soon after the *Discovery* had embarked. He was disingenuous by not revealing to the British Government the need for a relief expedition in the first instance.

The total funds available for selected expeditions and the relative costs of their vessels expressed as actual figures at the time (in British Pounds) and converted to current value are shown at Table 2. These values were determined using a calculator for major project costs in history that includes factors for wage levels, purchasing power, gross domestic product and opportunity cost (Officer & Williamson, 2006; MeasuringWorth.com, 2012). The table demonstrates that *Discovery* was the best-funded expedition of its time by a significant margin and that it was normal for around half of the expedition funds to be spent on the vessel.

| Expedition | Total Funds (converted to £) | Vessel Cost (converted to £) | Total Funds 2012 equivalent | Vessel Cost 2012 equivalent |
|---|---|---|---|---|
| *Belgica* [1] | £13,648 | £5,648 | £10,600,000 | £4,370,000 |
| *Southern Cross* [2] | £40,000 | £5,000 | £30,900,000 | £3,870,000 |
| *Discovery* [3] | £93,000 | £51610 | £72,000,000 | £39,900,000 |
| *Morning* [4] | As above | £3880 | As above | £3,003,000 |
| *Terra Nova* | As above | £20,000 [9] (1903 cost) | As above | £15,480,000 |
| *Gauss* [5] | £60,000 | £29000 | £45,300,000 | £22,400,000 |
| *Antarctic* [6] | £6,018 | £1368 | £4,660,000 | £1,060,000 |
| *Scotia* [7] | £36400 [8] | £16,730 | £28,200,000 | £12,900,000 |

Table 2: Relative cost of expeditions and vessels 1898-1904 using historic "Project" value calculator (Measuring Worth, 2012). (Bryan 2011, p. 129 [1], 138 [2], 145 [3], 155 [4], 174 [6], 183-5 [7]; Drygalski 1989, p. ix [5]; Salveson 1998, p. 61 [8]; Pound, 1966, p. 107 [9]).

The German South Polar Expedition's fundraising effort also relied on institutional support, patronage and the potential national prestige attached to possible geographical and scientific achievements. After a meeting of the German Joint Committee in April 1897 a three-man action committee was formed to raise funds through the country's centres of learning but the strategy failed to raise any significant funds (Yelverton, 2000, p. 9). The German expedition ultimately received funding of DM1.2m (about £60,000 at the time) directly from the Reichstag (Murphy, 2002, p. 72).

The end of the Victorian era was a time of small, individual ship-based expeditions that were financed on a case-by-case basis by philanthropy or government grants. This was the pattern until after World War II when there was shift to permanent, national bases founded for scientific and strategic reasons with secure government financial backing (Fanning, 1981, p. 14). For the *Discovery*, the donation offered by Longstaff represented a turning point in confidence in the project, after which more support was forthcoming. The copious funds allowed construction of a custom designed ship for polar scientific exploration with sufficient set aside to purchase the best equipment, supplies and consumables available, and for handsome wage rates for the civilian scientists.

## 4.5 The expedition vessel as a scientific platform

There were few constraints on the construction of the *Discovery* and the abundant funding allowed an open hand for innovation. The vessel had three main functions. Firstly, the vessel was a system to deliver the expedition to Antarctica, so it had to be seaworthy under extreme conditions when required, with capacity to ship the crew of forty-six with materials and provisions for an extended stay in the Antarctic. Secondly, it had to be fit for coastal exploration in polar conditions, and able to endure the rigours of navigating in ice. Thirdly, it was to provide a suitable and well-equipped platform for science at sea, especially meteorology, oceanography and magnetic science. The utility of the ship for these functions, especially the last, is a success factor for polar frontier science.

Using Cook's voyages as examples, Sorrenson makes the compelling case that vessels used for geographical exploration and scientific enquiries are scientific instruments. "Just as the telescope expanded the science of astronomy and allowed astronomers to explore new worlds and make images of them, so too did the ship for geography and geographers" (Sorrenson, 1996). Ship borne exploration included science research at the periphery but relied on the metropolis for instruments (sextant, theodolite, telescope and timepiece), mathematical theory and the almanacs required for navigation. In Cook's case, longitude determination was by one of four methods available. They were an eclipse or a transit, eclipses of the moons of Jupiter, position of the earth's moon or the use of a timepiece. Longitude itself was an expression of location with respect to the metropolis, Greenwich, and could have only been developed by global series of observations upon which the almanac tables were developed. Accurate observations and charting of the elements of terrestrial magnetism were only meaningful if the location of the observation was known with precision. The link to the metropolitan centre was maintained throughout any voyage of exploration by the regular reference to Greenwich Mean Time as the standard for navigation calculations of longitude. In reference to Cook's *Resolution* and *Adventure,* Sorrenson states "… these ships were more than just vehicles or platforms for observers and instruments; they shaped the kinds of information observers collected" (1996). The same was true of the *Discovery*.

The following analysis of the ship's construction features was developed in the light of its prime purposes as an observing platform at sea and as a tool for exploration and delivery of the expedition to the planned field base. The German expedition ship *Gauss* was constructed at the same time and for the same purpose, so analysis of both ships informs the question regarding the extent to which scientific success relies on the expedition vessel. The German expedition vessel *Gauss* was appropriately named after the famous German polymath and magnetic expert who had developed new theory and mathematical descriptors for earth magnetism (Turner, 2010, pp. 114-123). It was designed to be large enough to accommodate men, stores and equipment for three years, but small enough to be agile in the ice. The construction philosophy for *Gauss* was seaworthiness for high seas and heavy weather of the South Atlantic and Southern Oceans, but with sufficient strength for ice navigation. It had a "peg-top" shaped hull similar to that of Nansen's *Fram,* designed and built by Colin Archer (1832-1921) in Norway. This hull shape was intended to prevent the vessel being crushed if icebound (Savours, 1992, p. 19). The barquentine rig, with fore and aft sails on the main and mizzen masts allowed a smaller crew, as less manpower was required for sail handling than on a fully ship-rigged (square rigged) vessel. On *Gauss* the magnetic instruments for observing at sea were adjacent to the bridge. Both ships had biological laboratories and winches with drums of wire for deep-sea sounding and water sampling. *Gauss* had a photographic dark room (Bruce, 1901).

In contrast, a conservative approach to the design of *Discovery* was implemented. Scott wrote: "The committee, therefore, after due deliberation, decided that the new vessel should be built more or less on the lines of the old *Discovery*" (Scott, 1905b. p. 46). The ship committee included admirals, many of whom were Arctic veterans (Savours, 1992, p. 14) and the Chief Constructor of the Admiralty designed and oversaw construction. He wrote that a "peg top" design was considered for *Discovery* but:

> After full consideration it was decided that, having regard to the many thousands of miles of tempestuous seas the new vessel would have to traverse both outwards and homewards, it would be better to have an ordinary ship-shaped section, as being more conducive to general goodness of behaviour under trying sea conditions.
>
> (Smith, 1905, p. 4)

Table 3 provides details of the vessels for comparison expressed in the dimensions used by constructors.

| Feature | *Gauss* | *Discovery* |
|---|---|---|
| Length | 151 feet (46 m) | 172 feet (52.5 m) |
| Beam | 37 feet (11.3 m) | 33 feet (10 m) |
| Tonnage | 1450 tons (1473 tonnes) | 1570 tons (1595 tonnes) |
| Rig | Barquentine (Square rigged on fore mast, fore and aft sails on main and mizzen masts) | Barque (Square rigged on Fore and main masts, fore and aft sail on the mizzen mast) |
| Power | 325 hp (242.5 kW) | 450 hp (336 kW) |
| Engine type | Triple expansion steam | Triple expansion steam |
| Speed | 7 knots (13kph) with a predicted consumption 5 tons of coal per hour. | 7 knots (13kph) with a predicted consumption 6.5 tons of coal per hour. |
| Ship yard | Howalt's Works, Keil, under direction of the Construction Department the German of Imperial Navy | Dundee Shipbuilders' Co. in the Panmure shipyard, under superintendence of W. E. Smith, Chief Constructor of the Admiralty with direction from the Ship Committee |
| Ship's Complement | 30 | 46 |

Table 3: Ship details (Drygalski, 1989, p. ix; Savours, 1992, p. 9; Markham & Holland, 1986, p. 26)

Both ships had three layers of planking making over 25 inches (64 centimetres) thickness at the waterline. On *Gauss* there were additional steel plates to protect the stem and the stern, whereas on *Discovery* plates protected the stem only. The twin bladed propellers, and rudders that both could be detached and withdrawn into wells in the ship to protect them from ice damage were common features. The advanced triple expansion steam engine built for the *Discovery* was rated at 450 horsepower (Smith, 1905) but actually generated 570 indicated horsepower when on sea trials (Bryan, 2011, p. 147).

*Gauss* had a system to circulate hot water near the seawater intake for the boilers, a mechanism to prevent freezing of the feed water and blockage of the pumps. *Discovery* was considered unsinkable, having numerous watertight bulkheads that ensured buoyancy if ice breached the hull. Tanks on *Discovery* served a dual purpose as coalbunkers on the outward trip, and then as water ballast after the ship was unloaded. The primacy of magnetic observations at sea was the rationale for the timber fabric of both ships. Figure 3 from the *Sphere* newspaper shows the generalised layout of the ship, but note that the magnetic observatory is incorrectly illustrated as an independent structure on the fore deck. Its correct location is illustrated at Image 2 below.

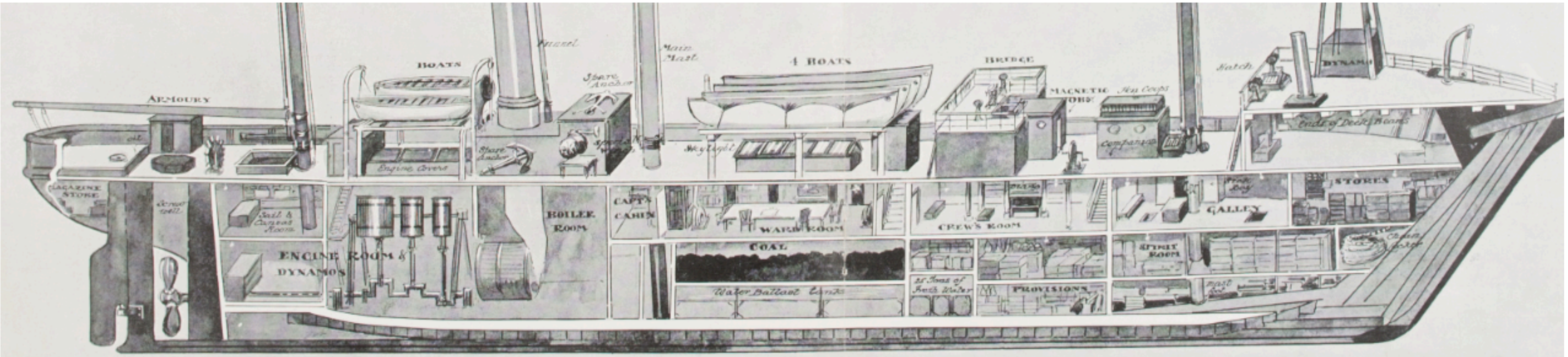


Figure 3. Schematic of Discovery general layout (The Adventurous Journey of the "Discovery" Towards the South Pole, 1901)

On *Discovery,* the magnetic observatory was a deck cabin (8' x 6' 6", or 2.4 m x 2.0 m) on the upper deck directly below the bridge deck. The bridge and observatory were interconnected by a speaking tube to facilitate alignment of the dip circle on its gimbal stand along the magnetic meridian determined from the ship azimuth compass. Measurements of magnetic dip and intensity using the Lloyd-Creak dip circle issued to the expedition required accurate alignment. The magnetic observatory was removed during the refit of 1923-24 and the arrangement of the bridge is now vastly different to the original construction. The original can be seen on the builder's model at the RGS (Image 2) whereas the ship in the Dundee *Discovery* Museum retains the configuration from the refit.

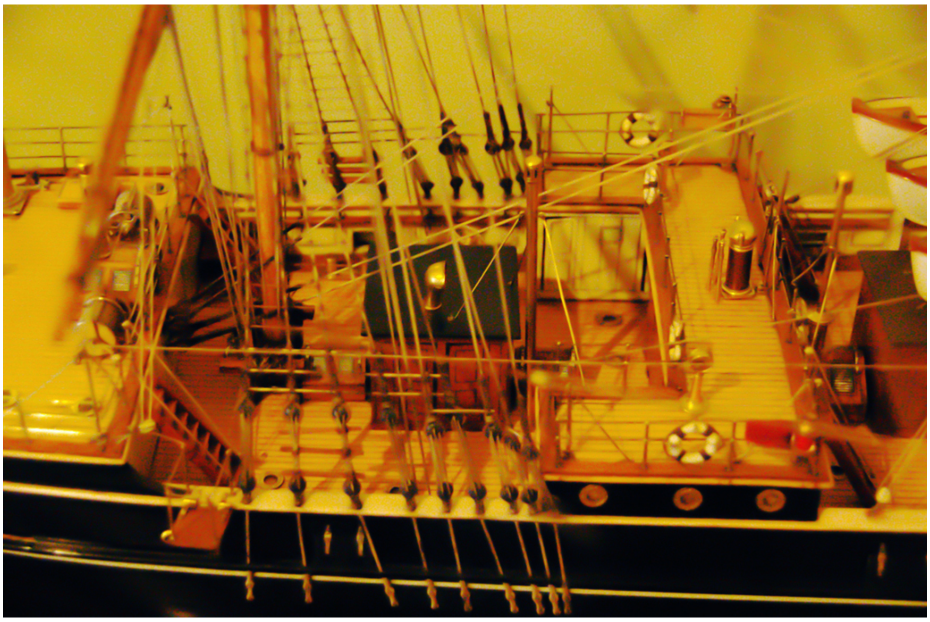

Image 2: Builder's model of the *Discovery* in the RGS, London. On the right hand side is the bridge deck, with life preservers visible on its rails. The magnetic observatory is below the bridge deck, directly beneath the brass-capped compass binnacle amidships. Note all metal fittings in vicinity of magnetic observatory are non ferrous and the shrouds of the standing rigging are hemp (not steel cable) and the deadeyes are wooden. Note also the biological laboratories below the forward facing returns of the bridge deck (with portholes) and the drums for sounding cables on the forecastle (author's photo).

The features of the magnetic observatory were described in detail at the lecture of the Forty-sixth Session of the Institution of Naval Architects in 1905, quoted in Appendix III, where the specifications are also found (Smith, 1905, p. 9). In common with *Gauss*, there was a zone of thirty feet (nine metres) radius around the magnetic observing station where only non-ferrous materials were used. No internal photos of the observatory exist, probably due to insufficient light for successful photography with equipment of the time.

Neither of these ships were perfect specimens of the shipbuilder's craft and both were examples of the compromise between seaworthiness and the capability to withstand ice pressure. *Discovery's* faults included the famous "Dundee Leak", a persistent inflow of water that was primarily due to the use of unseasoned timbers that shrank allowing ingress of water. The specified timber, greenheart oak, requires ten years of seasoning before use. In addition, the timber used was found to have abundant wormholes that allowed water to seep between the planks indicating: "…inadequate supervision during construction as the affected wood should have been rejected" (Bryan, 2011, p. 151). The builders recommended ironwood sheathing but they were overruled. Dundee had no stock of seasoned greenheart, whereas Archer, an alternate choice of builder, had an abundance of seasoned timber in Norway. Although the *Discovery* was designed after more than two centuries of development of design and construction of wooden ships, there were design flaws. The masts were incorrectly placed and were too short, making the ship under-canvassed and therefore underpowered under sail. Scott mentioned that the ship would have been better for more headsail, and the masts should be stepped further forward as the ship carried more weather helm than desirable. The designer defended the sail plan stating that it was normal for polar vessels to be under-canvassed due to the difficulty of sail handling in polar conditions and the risk of losing top hamper in storms (Smith, 1905, pp. 14-15). The location of the masts was rectified during the refit of 1923-24 and before Mawson used the ship for his British, Australian, Antarctic Research Expedition (BANZARE, 1929-31). The steam power was adequate, but there was alarmingly high coal consumption that ultimately limited some of the exploration work. Internal strengthening made *Discovery* a stout vessel, able to survive the two years in the ice at Hut Point (Jones, 1980). Short masts and lack of top hamper meant the *Discovery*'*s* roll was more pronounced than it would have been with the stabilising influence of more sail. The incorrect placement of the masts and the short sail plan also meant that the helmsman had to compensate for unbalanced power between the fore and aft of the ship under sail. The small rudder, limited in size by the need to draw it into the deck well, made this compensation a challenge.

Introductory notes to the translation of Drygalski's narrative of the German South Polar expedition reveals that the *Gauss* had shortcomings also. She was underpowered and slow, averaging only four or five knots, compared to the predicted speed of seven. She was unstable at sea, very dark below decks, the pitch insulation between decks melted in the tropics and dripped tar into the living spaces, the steam winches were too underpowered to lift the main anchor and, critically, the funnel interfered with the boom of the main mast. In addition, the ship steered poorly, mainly due to the small size of the rudder whose dimensions (like *Discovery*'*s*) were regulated by the size of the well into which it could be retracted (Drygalski, 1989, p. x).

Bruce, after farewelling the *Gauss*, predicted that she would be the more iceworthy ship, and the *Discovery* would be more seaworthy (Bruce, 1901). Both ships were seaworthy for the long passages to Antarctica and back, but extreme rolling caused discomfort, especially on *Discovery*, and both were slow, even under sail and steam. Both ships survived being ice-bound, but *Gauss* suffered a more rigorous test having been caught in unprotected waters.

## 4.6 Instructions and expectations

Instructions to the expedition came from a number of official and non-official sources. The top level of guidance to the operations of the *Discovery* was in the two sets of instructions drawn up for commander and scientific director respectively. These documents were instruments of the RGS and RS joint organising committee and were countersigned by members on 20 May 1901 (British National Antarctic Expedition, 1901).

### 4.6.1 Evolution of the official instructions

Instructions such as these are germane to the success of the scientific or exploratory elements of any voyage of reconnaissance and inquiry. The boundaries of responsibility and power of the leaders are specified and the agenda for activities and logistics is explicit. In the case of Ross, the instructions (drawn up by the Admiralty, but most likely formulated by Ross himself) leave no doubt regarding the high value placed on accurate, complete and sustained performance of magnetic science throughout the expedition. The *Discovery* instructions do not provide the same wealth of theoretical or practical background information related to the performance of magnetic science, but they do clearly stress the operations of the magnetic program and its priority over other disciplines.

### 4.6.2 Gregory's plan of operations

During 1900 Gregory was developing plans for the scientific program of the expedition even before his appointment was confirmed. In a series of letters during that year he outlined his intentions for the scientific program (and recruitment of the civilian scientific staff) that vary greatly from the final instructions, and from the operations that resulted under Markham and Scott's leadership. One cannot gauge whether Gregory misunderstood Markham's motivations and supreme control over the expedition preparations (this is unlikely) or whether he was optimistic that his own agenda might prevail. It was inevitable that there would be direct confrontation and it was a confrontation between the RS and Markham of the RGS, rather than between Gregory and Scott (Leake, 2011, pp. 65-70).

The first and most detailed outline of Gregory's proposed program was by letter to Edward Bagnall Poulton (1856-1943), the senior RS representative on the expedition's Joint

Organising Committee, on the assumption that the RS was in control of matters related to science (Gregory, 1900a). His subsequent correspondence to Markham conveys a tone of surprise that Poulton is not the conduit for communication on scientific matters. Gregory's follow up correspondence seeks confirmation of many of the elements laid out in his proposed planning and logistics in the Poulton letter. Markham failed to respond in a manner that clarified Gregory's concerns and he assumed that silence on certain matters indicated agreement. A schedule of five cruises in a campaign spanning 1901 to 1904 included the possibility of the ship only overwintering in the Antarctic ice pack during one winter season, after dropping a scientific party in McMurdo Bay. Explicit separation between work of a landed party and work of the ship at sea is detailed and Gregory is clear about his intention to gain the maximum benefit of the vessel's utility for marine science. The schedule of proposed cruises was:

- Cruise A-October 1901 to March 1902 coasting Wilkes Land
- Cruise B-After resupply in Melbourne, depart in April 1902 and continue along former line, or follow a similar but more northerly transect until September 1902.
- Cruise C- After further resupply in Melbourne depart in November 1902 and steam to McMurdo Bay and land a party to remain until early 1904. In the meantime the ship carries on scientific work in the high latitudes south of the Pacific, returning to Melbourne or New Zealand by January 1904.
- Cruise D-Work of the land party is described here and includes establishment of high altitude meteorological stations on Mount Erebus or Mount Terror, and a sledge journey to the south magnetic pole. Land party to be ready for pick up by 8 February 1904.
- Cruise E-Voyage back to England with remaining scientific work in the zone north of the ice pack and across the Atlantic or Indian oceans.

Cruise A was intended as a shakedown trial for all equipment and sledging kit if a brief landing of less than ten days was made in Wilkes Land. The remaining work at sea would include magnetic and meteorological observation, geographical surveying, biological collection from all depths, chemistry and temperature of seawater and the collection of deep-sea deposits, boulders and erratics dropped by icebergs. The landing party would concentrate on meteorological observations at the Winter Station, magnetic observations and determinations of the precise locality of the south magnetic pole, geodetic work, records of tidal variation, seismic observations, biological collecting, investigation of the physics of glacier ice and determination of the geographical and geological structure of the Antarctic land mass. After some notes regarding recruitment of the scientific staff the proposal moves to equipment and logistics. Dog teams are considered vital and, in the event of a "naval party" being landed as well as a scientific party, there must be provision for the scientific party to have first call on sledges, dogs and equipment. Gregory stressed the importance of early recruitment and preparation:

> I should not care to join the expedition unless it be possible to secure a scientific staff of men who are equipped with the training of experts and who are inspired by scientific enthusiasm, and unless the conditions are as favourable as possible to efficient work. And efficiency in this expedition seems to me to depend on an adequate grant for scientific equipment, sympathetic cooperation with the naval staff and ample time before hand for preparation study and experiment.
>
> (Gregory, 1900a)

Gregory then commented on the manner in which an early agreement regarding scientific analysis and publications of the scientific collections should be handled and expressed the opinion that editorship of the publications should be managed jointly by a member of the scientific staff with a member of the Joint Committee. He proposed that the relations between the Captain and the head of the scientific staff should be precisely defined and explicit, in written form, and addressed to both. The acquisition of instruments and polar equipment and recommendations for inclusions in the expedition library are mentioned before closure of the proposal. Although this scheme is not strictly a set of instructions, it is a guiding document that, in other circumstances, might have been used to formulate comprehensive instructions similar to the Admiralty instructions to Ross.

Disagreement over the instructions to the expedition, especially with respect to the leadership and control, was the issue that precipitated Gregory's resignation in May 1901. Gregory had always imagined that the task of the ship's commander was to provide support and logistics for the scientific program and that the commander would act in a subordinate, or at least a collegial role with director of the civilian scientific party.

> The captain would, I hope, be instructed to give such assistance from the crew as may be required in dredging, low [sic] netting etc., to place boats when required at the disposal of the Scientific Staff, if possible, and to consult with the Scientific leader as to the route to be followed, in case deviations may be advisable to pursue any line that promises to yield interesting results.
>
> (Gregory, 1900a)

Gregory's assumptions are further revealed in a subsequent letter to Markham where he wrote: "I presume that I should be in command of the land station & the sledge work" (Gregory, 1900b). His final letter to Markham in this correspondence about work and management of the expedition was written in London after Gregory returned from his professorial post in Melbourne to finalise planning and organisation for the expedition (Gregory, 1900c). Gregory discussed the limitations that landing a shore party early in the Antarctic summer would place on the capability of the ship to carry out coastal exploration and science. He raised the possibility that the ship might be caught in pack ice early in the season in which case nominal scientific results would be gained, and although it was possible they might be brilliant, the scope of operation would be limited. Gregory viewed the land party as only one element of an extensive scientific program covering a range of disciplines. Only one reference appears in his correspondence regarding an attempt to achieve a sledge journey to high southern latitudes, and this is regarding the advisability of using dog teams for transport as "every extra pound of food that we carry will enable us to go four miles further south." Gregory also suggests a sledge journey to the south magnetic pole in the austral spring of 1903 as an activity of his proposed "Cruise D" (Gregory, 1900a).

Markham almost immediately moved to cut off Gregory's control of, and involvement with, the expedition when he responded in a sarcastic tone clarifying his own conceptions of the arrangements for the leadership and management, and effectively inviting Gregory to resign.

> I am exceedingly sorry if you have been inconvenienced and led to suppose that the organisation of the expedition was other than what it is, and must be. I thought my views were perfectly well known through my many addresses and lectures.
> I have always maintained that the expedition should be a naval one.

He continued "I much regret the loss of your services if this is to be" (Markham, 1901b). This was not the final example of control over the official expedition instructions exerted by Markham.

**4.6.3 Directives in the official instructions**

The final official instructions to the scientific director are brief and provide little practical guidance. Point three states "You will direct the scientific work of the gentlemen who have been appointed to assist you" and point four names them. The subsequent points encourage cooperation between the scientific director and the Commander "to secure the success of the enterprise" but there is no statement of objectives so there is no guide as to what might constitute "success." All collections, logs, journals, charts, drawings, photographs, observations and scientific data would be the joint property of the two societies and the scientific director was expected to superintend their distribution, analysis and preparation for publication, as well as making contributions to the official narrative of the voyage. Staff could not communicate with the press and no personal narratives, magazine or journal articles may be published until six months after the official version was released. The scientific director, with concurrence of the commander may fill any vacancies arising, and scientific staff travel at their own risk (British National Antarctic Expedition, 1901).

The sections of the instructions to the commander relevant to scientific programs are paraphrased here. The objectives are firstly, to determine the nature, condition and extent of the polar lands within the scope of exploration and secondly, to make a magnetic survey of southern regions to the south of the fortieth parallel and to carry out biological and physical researches. Executive officers of the ship under the commander's immediate control would be responsible for magnetic and meteorological observations, astronomical observations, surveying, charting and sounding operations. The scientific director and the civilian staff are "under your command" but open communications and consideration as a colleague was to be maintained. The success of the expedition as a whole would rely on "harmonious work and hearty cooperation." Point seven addresses magnetic science and notes that magnetic instruments for use on board and ashore have been provided, and that Captain Ettrick Creak (1835-1920) had drawn up instructions for their use, and he, and Kew observatory had provided training. This refers to the section on magnetism contained in George Murray's (1858-1911) *Antarctic Manual* (Murray & RGS, 1901, pp. 19-30). Comments regarding the specialised construction of the ship and its magnetic observatory led to "We, therefore, impress upon you that the greatest importance is attached to the series of magnetic observations to be taken under your superintendence, and we desire that you will spare no pains to ensure their accuracy and continuity." Mention is made of desired observations at sea between the Cape and the Antarctic base station, and south of the fortieth parallel. Some points on exploration and other disciplines follow then at point eleven magnetic and meteorological work are again mentioned as "you will follow the programme arranged between the German and British Committees, with the terms of which you are acquainted." Deep-sea soundings, dredging, water sampling and biological collection were to be carried out as often as possible according to the directions contained in Murray's *Antarctic Manual*. Instructions regarding logistics include proceeding to Melbourne or Lyttelton then coastal Antarctic exploration and identification of a suitable landing place. Points 17 and 18 relate to the work to be carried out in the event of overwintering the ship in Antarctica. Support for the scientific team was to be provided by allowing "all facilities for the prosecution of their researches." Point 19 discussed operations in the event of the ship not overwintering but leaving behind a landed party on the ice. Hints regarding outcomes were contained in the Point 21 statement "…we fully confide in your combined energy and prudence for the successful issue of a voyage which will command the attention of all persons interested in navigation and science throughout the civilised world." Instructions regarding ownership of the intellectual properties are similar to those stated in the instructions to the scientific director. After some details of ship registration, insurance and alternate leadership in case of misadventure, the instructions close with motherhood statements to impress the importance of the venture on the commander including "The *Discovery* is the first ship that has ever been built expressly for scientific purposes in these kingdoms" and "The Expedition is an undertaking of national importance: and science cannot fail to benefit from the efforts of those engaged in it" (British National Antarctic Expedition, 1901).

The instructions became as confused as the roles of the commander and scientific director after the considerable wrangling between the two societies regarding the contents of the instructions between January and May of 1901. The main issue of contention was regarding the commander's prerogative to overwinter the ship in Antarctica, and the balance between exploration and science that would be tipped by any decision on the overwintering decision. Gregory had indicated that the investment in the vessel would best be repaid by dropping a land party for continental exploration and science, thus freeing the ship to make the various marine surveys he detailed in his proposed plan of operations. Overwintering the ship in the ice limited the science program at sea but served Markham's unspoken agenda of a geographic South Pole bid, or at least high southern latitude trek.

Markham's personal notes record the sequence of committee activities and correspondence between the societies regarding the disagreement over his first draft of instructions presented in January 1901. He detailed his version of events in his memoirs as *The Attempt to Wreck the Expedition* (Markham & Holland, 1986, pp. 133-141). The Joint Committee was in disarray, and the balance of power shifted to the RGS by resignation of three key members in response to their disapproval of the proceedings of the committee (Yelverton, 2000, p. 49).

Minutes of the RGS Council meeting of 17 April 1901 provided the justifications for rejection of the RS version of instructions. They comment on the issue of landing a separate party then retreating north with the ship:

> The existing difficulty has mainly arisen from the fact that only a single ship is to be employed; but as the funds of the Expedition do not at present admit of the employment of a second vessel, it seems essential to make the best of the situation and to adopt such a policy as will not practically defeat either of the two primary objectives, for the attainment of which the Antarctic Fund has been subscribed.
>
> In making the above remarks, the Council of the RGS do not ignore the importance of a geological investigation of the volcanic regions, or of biological and other researches on shore. On the contrary they are inclined to believe that these objects may be more fully secured by the entire strength of the Expedition than by a very small detached party, which may be thrown out of action by the death or sickness of one or two of its members.
>
> (RGS, 1901)

The matter of the intent of the instructions and the free hand of the expedition commander regarding logistics was finally settled in early May 1901 with the collateral damage to the prospects of the expedition being the resignation of Gregory. Yelverton covers the episode in detail and concludes that with just eight months left before departure "The entire debilitating diversion from the business of organising the expedition, which nearly robbed it of the man chosen to lead it, had effectively removed the man who would have been Scott's most influential aide at the most crucial stage of procurement" (Yelverton, 2000, p. 51). Scott was also on the verge of resignation, but they both rose above the acrimony between the societies and remained on cordial terms (Leake, 2011, p. 70).

### 4.6.4 The *Antarctic Manual*

The second level of instruction to the scientific program is found in Murray's *Antarctic Manual* (Murray & RGS, 1901) with a section on terrestrial magnetism written by Creak (Creak, 1901d). The objective of securing the most complete set of observations as circumstances permit is explicit and general comments regarding the magnetic observatories for determination of the constants of the instruments (Kew and Melbourne), and establishment of an Antarctic base station are followed by:

> observations of the magnetic elements at sea are of great importance. It is with this view of the value of such observations that the ship has been specially designed, with every cause of disturbance from iron eliminated within a radius of 30 feet from the centre of the ship's observatory.
>
> (Creak, 1901d, p. 20)

Separate lists of instruments provided for the on-board and ashore work precede general instructions for making the observations.

For low latitude land station observations the techniques for operation of the unifilar magnetometer, Barrow's circle, the Lloyd-Creak Circle and Fox circle are not provided as they were available in the *Admiralty Manual of Scientific Enquiry*, and special instructions for the Eschenhagen variometer would be supplied separately. Reference is made to standardising instruments at the Cape of Good Hope (although the Cape is not mentioned as a waypoint in the Joint Committee official instructions) and Melbourne. These operations were critical as "The value of the observations of Intensity in Antarctic regions with Lloyd's needles is dependant upon the accuracy with which these base observations are made." The Antarctic base observations and those to be made on sledging journeys are specified, with mention of the term days agreed for synchronous observations. "As complete a magnetic survey of the neighbourhood of this Southern base as possible should be made…" (Murray & RGS, 1901, p. 22). Recommendations regarding the best instruments to use in different circumstances complete the section on Antarctic land observations.

Guidance regarding observations on board ship commences with reflection on the great value of observations to be made across the large tracts of open ocean. Observations on board would show the extent of deviation caused by ferrous elements of the ship, so methods of computing the corrections for declination, inclination and total force are included. Preferred areas of operation for magnetic observations at sea are specified, notably between the Cape and Melbourne at a latitude of 40° S. and the general instructions include a number of items of importance to the magnetic program:

- Swing the ship for compass deviation as often as possible
- Declination should be observed twice daily at sea when the sun's altitude is below 30°
- Methods of operation for the Fox circle at sea are specified
- Dip and Force should be observed daily at sea, and twice daily in high southern latitudes
- Charts of declination and total force are supplied and must be considered approximations of the truth, but may be an aid to determining the appropriate weights to be used on Lloyd's needles for force
- Comparison between disturbances of the needle on board compared to on the ice is a worthy enquiry
- Forms are supplied for recording observations with sufficient quantity to send duplicates back to England as opportunity arises

The final section of the terrestrial magnetism instructions in the manual relates to international cooperation for the years 1902 and 1903. This section mentions the simultaneous observations of the magnetic condition of the earth using observing stations "…distributed over the globe with a uniformity never before attained" (Murray & RGS, 1901, p. 28) and the continuous and term day observing regimes are specified.

Further instructions for the physicist regarding seismology, pendulum studies for gravity, atmospheric electricity, astronomy (including special instructions for the solar eclipse of September 1903) and observations of the aurora are found amidst lengthy notes on climate and meteorology, chemical and physical seawater analysis, geology, vulcanism, ice observations, zoology, botany, sledge travel and geography. Although the volume includes selections of narratives from earlier explorers including Wilkes and d'Urville, no extract appears from the narrative of Ross.

### 4.6.5 Agreed protocols with the German South Polar expedition

A third level of documents providing guidance to the scientific team on *Discovery* is correspondence and records of agreement between the organising committees of the BNAE and the German South Polar Expedition. These are detailed agreements regarding instruments, planned observations at sea and at land-based observatories, term days and hours for synchronous observations, general background comments and the formulae to be used for data reduction. At the International Geographical Congress of 1899 in Berlin, the German Commission announced that, with respect to cooperation between Germany and England "a perfect understanding exists regarding the proposed terrestrial-magnetic and meteorological programme for the South Polar expedition. As regards the Magnetic Programme the differences are of little or no importance" (International Geographical Congress, 1900). The minutes of the (German) sub-committee of the Scientific Council for Meteorology and Terrestrial Magnetism from the 24 November 1899 meeting (translated by Mill) contain the protocols for observations of the three magnetic elements at sea on a daily basis. Arrangements for the land stations in Antarctica, such as maintaining constant temperatures in the observation huts and determining the constants for the registering apparatus precede guidance about measuring intensity during overland journeys. The kit of instruments for the land stations (Kerguelen and Antarctica) as well as those considered suitable for overland travel are all specified. Prospective cooperative relationships with Argentina (Staten Island), the US (Alaska and Honolulu) and the Swedish expedition are discussed, in addition to the British contributions from Melbourne and Cape Town observatories. Detailed instructions are provided in relation to meteorology (Sub-Committee of the Scientific Council for Meteorology and Terrestrial Magnetism, 1899).

A more detailed report by the English including the exact make and quantity of magnetic instruments and prospective observing sites was written about the same time (but the archive is undated), and assumes the ship (*Discovery*) would not remain in the south over winter (Antarctic Expedition, n.d.). The header specifically stated this information is to be communicated to the German Antarctic Committee. The invention of the Lloyd-Creak magnetometer to solve the difficulties in determining the magnetic force (intensity) at sea and the design of the magnetic observatory on board were both mentioned. This document indicates the intention to make Melbourne the expedition's magnetic base station and that the land party in Antarctica would probably be in the vicinity of Cape Adare. This report has similar conclusions to the German sub-committee's regarding instruments and types of observations, but meteorology is not included. Drygalski's letter to Markham of 25 February 1901 indicates that German vessels in the Southern Ocean during the observing period will be requested to maintain observations for magnetic deviation and meteorology and he asks that Markham request similar arrangements for British vessels (Drygalski, 1901). No archival material confirms Markham made any formal arrangements opf this type.

All the elements of the British magnetic program are condensed into one comprehensive document, the *Programme of Scheme of International Observations of Terrestrial Magnetism During the Period of Antarctic Research. 1902-1903*. The object of observations is to "…procure a series of synoptic charts which will allow of the variations in the magnetic condition of the whole earth being traced in detail during a definite period, and so to provide the necessary basis from which alone the fundamental problems of terrestrial magnetism can be more clearly approached" (British National Antarctic Expedition, n.d. b).

The historic and cultural contexts reviewed early in this chapter influenced the ultimate success or failure of the scientific program of frontier polar expeditions of scientific exploration around the turn of the twentieth century. The RN expeditions on which the *Discovery* was modelled were mostly large expeditions, focused on exploration, not science and related to the mercantile interest in a North-West passage trading route to the Orient. In spite of their long tradition of British scientific exploration, the RN and the British government were disinterested in Markham's vision of an Antarctic expedition until it became clear that there was strong institutional and philanthropic support, and that other nations might cause embarrassment by pre-empting the British.

Terrestrial magnetic science had grown more sophisticated during the Victorian era with advances in mathematical modelling and better instruments, but there had been no leaps in theory to explain the sources of the observed phenomena. Patronage and institutional support for the expedition were necessary elements used by Markham during the evolution of the expedition to acquire funding. The expedition was lavishly funded by virtue of the prestige brought by the RS involvement and the initial prospects of abundant, high quality scientific research. Significant investment was made in the vessel to support both exploration and research and commissioning the construction of the vessel was the first operational step of the expedition.

International collaboration with the German program in meteorology and terrestrial magnetism commenced well through frequent and clear communication between the organising committees. The prospect of combining data from the Swedes, Americans and Argentinians added opportunities for an unprecedented network of magnetic observations across the southern hemisphere. There was no shortage of general instructions to the physicist regarding the magnetic program but the contribution by the RS to the scientific program diminished progressively from the moment of its first involvement. Instructions to the commander of the expedition (as ultimate leader) gave an open hand regarding logistics and the program of operations. The thesis now moves to description and analysis of operational matters commencing with recruitment and training of the scientific practitioners before progressing to the first phase of the expedition work, science at sea.

# Chapter 5: Commencement of operations and maritime science

Dr Charles Chree (1860-1928), Superintendent of the Observatory Department of the National Physical Laboratory, stated in his 1908 presidential address to the Physical Society of London:

> When referring to any British national undertaking, such as a war or a scientific expedition, one is expected to apologise for a greater or less amount of preliminary muddle. Perhaps as a variant I may be allowed to say a few words as to what should in my opinion be done when the next National Scientific Expedition is being prepared…All the apparatus for the expedition should be ready and thoroughly tested at least three months before the expedition sets out, and the observers should use this apparatus sufficiently to become entirely at home with it. A programme [for each subject] should be drawn up and the observers practised in its execution…The necessity for a programme would no doubt be lessened if the expedition were under the command of a Physicist of resource and ripe experience…It might also serve a useful purpose [] if, on the return of the expedition and after a general examination of its results, something equivalent to a scientific court-martial were held by a competent judicial body whose expressions of approval or blame would carry weight.
>
> (Chree 1908b)

Chree was among the first rank of physicists in Britain and although he had contributed significantly to the the scientific report on terrestrial magnetism from the *Discovery* (Royal Society, 1909) these comments were directed at what he perceived as deficiencies in preparations and they probably disturbed Scott, as they came at a time when his second (*Terra Nova*) expedition was in preparation and fundraising relied partly on scientific credibility.

With the exception of construction of the expedition vessel discussed above, this chapter considers the first active operational steps of the expedition including the recruitment and training of key scientific staff. It then moves to the events that unfolded during the outbound voyage to New Zealand, the first phase of the expedition's scientific work.

Research commenced soon after the departure from Cowes on 6 August 1901 and evolved during the passage through the Atlantic, across the Indian and Southern Oceans, then south from Christchurch to the Ross Sea. The mettle of the scientists, the ship and the equipment were tested early in the voyage.

## 5.1 Pre-departure preparations, recruitment and training

It is self evident that the quality and quantity of an expedition's scientific work relies on the skills, knowledge and diligence of the scientific staff. Skill can be assured by selection and training but experience must be gathered: both are necessary for quality scientific inquiry. Recruitment commenced in Markham's mind long before the funding was secure or construction of the vessel had commenced. He had been considering potential RN officers since at least 1887 (Markham & Holland, 1986, p. 3) and secured the services of Scott as commander in mid 1900, about six months after Gregory had been offered the scientific leadership position. This marked the commencement of a "top down" process to fill the positions of the officers, crew, civilian scientific staff and a handful of others. This section reviews the recruitment criteria and training strategies, then assays the effort made to find competent scientists that were well suited to fieldwork in an extraordinary environment.

### 5.1.1 Recruitment processes

Appointment to the scientific staff of a large, well funded polar expedition supported by sponsorship from learned societies was a prestigious position in 1901, as it is now. Such a position provided opportunities for personal scientific achievement and public recognition. For the *Discovery*, staff were mostly brought to the attention of the management committee by interested parties and most were engaged by direct offers. No public or transparent process was undertaken to find applicants for key positions.

### 5.1.2 Positions

The complement of the *Discovery* for most of the expedition was around 45. The commander of the vessel became the overall leader of the expedition but the position of director of the civilian scientific staff had initially been at the top of the hierarchy. The commissioned officers who made up the wardroom were the commander, lieutenants, and the chief engineer. There were two surgeons who doubled in a scientific research capacity. The dual role of these men reflected the tradition of RN naturalist surgeons, although in previous times they would have been officers, not civilians. Other scientists included a marine biologist, a geologist, and a physicist. Ships officers had duties in relation to meteorology, sounding, dredging, seawater analysis, hydrography and cartography. Non-commissioned crew (the lower deck) ultimately took on a range of scientific duties at sea and ashore in Antarctica, especially for meteorological observations. Members of the expedition's Joint Committee countersigned official letters of appointment, but neither that committee, nor the sub committees demonstrated any real influence in the selection process.

### 5.1.3 Selection of leaders

There are different versions describing Scott's recruitment as commander of the expedition. In his narrative, *Voyage of Discovery* he describes an accidental encounter with Markham on the streets of London, an invitation back to Markham's rooms where he was made familiar with the position, then a subsequent successful written application (Scott, 1905b, Vol. 1, p. 32). Markham's notes show that he mused at considerable depth on the qualities required for the role of commander and who amongst the crop of RN officers might fit those criteria and who might also be released from the Navy at the time (Markham, 1898b). Gregory had proposed that an ice master and crew with high latitude experience might best be found amongst the Dundee whaling fleet (Gregory, 1900a) but Markham was explicit in his preference for an RN commander and crew. Markham's archives contain his criteria for selection:

> The appointment of a leader to the Antarctic Expedition is the most important step of all. He should be a naval officer, he should be in the regular line and not in the surveying branch, and he should be young, not more than 35; but preferably some years younger than that.
>
> All previous good work in the Polar regions has been done by young officers in the regular line; those in the surveying branch who have been employed on polar service, have been failures. Old officers, all past 40, have failed and have been unable to take the lead in expeditions they nominally commanded. They are physically unfit. (Markham, 1898b)

Markham's analysis covered a dozen potential RN officers and Scott was not his first choice. Captain George Egerton (1852 –1940) is described by Markham as " the '*beau ideal*' of a polar commander in every respect, a born leader of men" and "the best man afar and away" except for his age (46). He declined Markham's offer. Commander John de Robeck (1862 – 1928) was the second choice but the Admiralty declined to release him. Scott fitted Markham's preference for a young lieutenant trained in the torpedo school. "All the experience of the past warns us against selecting a commander who is over 35, or who has been brought up in the surveying branch" (Markham, 1898b, p. 38). Scott admitted having no inclination towards scientific or polar exploration. He was supporting his mother and sisters after his father and brother had died. Scott was only interested in forging a successful career in the Navy, and his best prospects were as a specialist in torpedo warfare. Markham worked alone to arrange the appointment of Scott. He wrote directly to the Admiralty specifically requesting the release of Scott for the expedition (Leake, 2011, p. 66). The Joint Committee had not been consulted but Goschen, First Lord of the Admiralty, assumed it was official, and that the request was the result of committee deliberations. The RS took umbrage at this slight of hand and it was an issue that almost caused their withdrawal from involvement with the expedition (Jones, 2011, p. 120). Scott's appointment was confirmed on 25 May 1900 although one harsh assessment states he had "no scientific training or expertise, had never led any expedition anywhere, had no experience in polar travel or skiing, had been chosen primarily to lead the race to the Pole and bring glory to the navy and the nation" (Leake, 2011, p. 66). The previous day had seen a factional fight in the Sub-Committee of Naval Officers, with a motion by the influential bloc comprised of Wharton, Tizard and Creak, that an alternate choice be appointed. The motion was lost and Scott was confirmed (British National Antarctic Expedition, 1899).

There were two ideal candidates for the scientific leadership: Bruce and Gregory. Bruce had an impeccable scholarly, expeditionary and field research background. He had developed an interest in natural history early in his academic career and, while studying medicine at the University of Edinburgh, he spent a great deal of time with the oceanographer Murray, analysing the collections from the *Challenger* expedition. This provided "invaluable training in both the taxonomy and the method of collating scientific data, and in assisting with the preparation of scientific reports and the necessary academic rigour that goes with the presentation of scientific findings" (Johnson, 2010 a, p. 18). Bruce joined the Dundee Whaling Expedition of 1892 (*Balaena*, *Active*, *Diana* and *Polar Star*) as oceanographer. In 1895 and 1896 Bruce gained extensive practical training in meteorological observing in extreme climates at the high altitude Ben Nevis observatory in Scotland with sub zero winter average temperatures. Bruce then joined the Jackson-Harmsworth Arctic expedition (1894-1897) as naturalist, travelling on the *Windward* relief voyage of 1896. On that expedition he performed considerable polar fieldwork and registered travel and survival experience. Subsequently, Bruce was engaged in scientific work (four hourly meteorological observations, seawater temperatures and some trawling) on the 1898 Arctic voyage of *Blencathra*. That expedition encountered *Princesse Alice,* the research vessel of Albert I, the

Prince of Monaco (1848-1922) by chance. Bruce learned a great deal from the meeting as the Prince was an avid oceanographer and his vessel was well equipped for the work (Johnson 2010a). Bruce wrote to Markham early in the *Discovery* expedition's preparations offering his services to the RGS expedition and summarizing his suitability for a position:

> For the past seven years I have been training myself with a view of making myself more efficient for Polar Service. I have spent one summer in the Antarctic Regions three summers and one winter in the Arctic Regions, and more than a year on the summit of Ben Nevis in charge of the observatory. I am a 'ski' runner and have taken part in sledging expeditions.
>
> In addition to my ordinary University training in mathematics, Physics, Chemistry, Botany, Zoology, Human anatomy, Physiology and Embryology, I have served in the *Challenger* Office under Dr. (now Sir) John Murray; as Demonstrator in Botany in the University of Edinburgh; and, as Demonstrator and afterwards assistant in Zoology in the School of Medicine of the Royal College of Surgeons and Physicians.
>
> (Bruce, 1899)

Markham responded on 17 April 1899 that no decisions had been made regarding personnel (Baughman, 1999, p. 29). Bruce waited for further advice from Markham, but in the meantime committed the *faux pas* of presenting his preliminary findings from the Jackson-Harmsworth expedition to the Royal Scottish Geographical Society, not the RGS. Mill wrote advising that the action was naïve:

> The RGS naturally wished to have the first news of your arctic work and as you went in my place I had expected you would have given the paper to the society that would not let me go! …But you don't realise how necessary it is to keep on cordial terms with such powerful corporations as the RGS if you hope to enlist their aid in helping you to subsequent expeditions.
>
> (Mill, 1899)

This partly explains Markham's poor treatment of Bruce as after nearly a year of waiting, Markham offered Bruce an assistant's place as naturalist on 21 March 1900, but not a leadership position (Bruce, 1900). Bruce declined then made his own expedition plans public.

Markham berated Bruce, “I am very sorry to hear that an attempt is to be made in Edinburgh to divert funds from the Antarctic Expedition; in order to get up a rival enterprise” (Markham, 1900b). Bruce successfully secured funding and the Scottish National Antarctic Expedition (*Scotia*) of 1902-04 was developed with almost purely scientific in its objectives (Johnson, 2010b). Bruce had been an ideal prospective scientific director for the *Discovery* expedition.

Gregory was also well suited to the work at hand. He was aged 35 and already had a considerable research and publication track record as well as extensive field experience when offered the post as scientific director of the expedition. He completed his First Class Degree in Geology in 1891 with a range of natural science subjects. He also studied simultaneously at the Royal School of Mines, wrote scholarly articles and lectured on geology and palaeontology (Leake, 2011, p. 6). Through a competitive process he gained a position as assistant at the BMNH in 1887 describing, cataloguing and collecting specimens. The scope of his publications broadened to include glaciology, coral reef formation and Darwin’s theories, then he undertook a study tour of museums and geologised around North America in 1890-91. He joined an expedition to East Africa in 1892-93 that was really a covert intelligence gathering and mapping enterprise, covertly sponsored by the British War Office. Gregory’s main role was surveying and mapping, and investigation of possible sources of mineral wealth (Leake, 2011, p. 20). Gregory had a personal interest in finding the cause of the trough that runs from the Dead Sea, down through the Red Sea and into Tanganyika. The “Great Lake Rudolf Expedition” fell into disarray through poor disorganisation and rampant ill health amongst the large cohort of indigenous porters and their leaders. Gregory, using his own funds, re-formed the remains of that campaign into a new scientific expedition. He headed inland from Mombasa to the region of Lake Baringo where he surveyed key features of the rift valley walls, recording topography, geological and archaeological features during a

1,650-mile (2,640 kilometre) trek over five months. This exploration and research generated many publications and coined the phrase “Great Rift Valley” (Leake, 2011, p. 27).

His DSc was awarded in his absence in 1893 on the strength of a major paper he wrote describing the geological history of the region extending from Malta, through France, Corsica, Italy, Switzerland and Austria using evidence from microfossils (Leake, 2011, p. 29). On his return from Africa he continued active involvement in learned societies, then joined Conway’s expedition to explore the interior of Spitzbergen (Svalbard) in 1896. “Gregory’s talents as an all-round biologist, geologist, geographer, mountaineer, skier and enduring walker, together with his keen interest in glaciation and its effects, his general amiability and proven toughness, undoubtedly explained his inclusion” (Leake, 2011, p. 42).

Gregory was in England when the executive granted approval of Gregory’s appointment to the expedition in November 1899 as scientific director of the *Discovery,* then departed for Australia to take up his new appointment as Chair of Geology at Melbourne University. Gregory arranged leave from his position at the university from November 1901 to March 1902, then from November 1902 to March 1904, in accordance with his proposed research voyages and assuming an overwintering party during 1903.

Scott’s appointment as commander in May 1900 brought a shift in Gregory’s status, his position was thereafter referred to as “Head of the Civilian Scientific Staff.” As a result his status in the expedition hierarchy became unclear, especially with respect to the supervision of the ship’s officers who were to be engaged in scientific work. Gregory continued planning from Melbourne then returned to England in October 1900. He travelled to Dundee to meet with Scott to clarify their roles. Gregory gave Scott a copy of his outline of the program sent to and believed that the return of the document the following day without comment indicated Scott’s assent, but Gregory’s confusion continued. Behind the scenes the Joint Committee was split into factions over the conflicting aims of the expedition. The essential problem was that the RGS under Markham's control was promoting exploration by making a polar trek the highest priority, which demoted the scientific program to second rank. This contradicted the intentions of the RS whose priority was naturally the scientific program. This matter also caused an internal split amongst the RGS members (Leake, 2011, p. 66). With the exception of a brief trip to the United States, Gregory remained in England until mid February 1901 and continued preparations and his attempts to clarify the program and leadership roles. During January 1901 Gregory had drafted the instructions he expected would become embedded as official by the Joint Committee, but was given a clear message of disapproval by Markham and Scott to the effect that Gregory would be subordinate to Scott and the civilian scientific staff were accessory and subordinate (Leake, 2011, p. 67). Gregory wanted to resign but representatives of the RS convinced him not to do so, as it would have been a complete victory for Markham. Just before Gregory was due to sail for Melbourne, a compromise was reached that included landing a small scientific party under Gregory's control. During the voyage he wrote a revised provisional version of the expedition plan that was published in *Nature* (Gregory, 1901c). A number of meetings of the Joint Committee were held after he left concerning whether or not there should be an overwintering party, and if so, should the ship remain in Antarctica? The RGS saw any obligation for the ship to install an overwintering party, then retreat north, as a possible hindrance to exploration, but the RS could not see how the main scientific objectives (a year's continuous magnetic and meteorological observations) could be achieved without a landed party. In the end "The RS gave way largely because the RGS had raised the major financial contributions, the impasse seemed unbridgeable, and no-one at the RS had the determination to match that shown by Markham" (Leake, 2011, p. 68). The Joint Committee approved the amendment at its 26 April meeting leaving it the commander's prerogative to decide whether there would be a landing party and whether the ship would stay in Antarctica over winter. Markham wrote to Alfred Kempe (1849-1922) the treasurer of the RS explaining the situation:

> As to the conference the main points we urge are
> 1. Freedom for the commander to prosecute exploration during both navigable seasons
> 2. Freedom for the commander to winter if he considers it necessary in the interests of the expedition and can find safe quarters.
>
> The order to land a party at the beginning of the season, and so waste precious time, is due to ignorance of Antarctic navigation on the part of Gregory and his friends.
>
> (Markham, n.d.e)

Gregory resigned his position after receiving a cable from Poulton with news of the committee's final decision. He later lamented that the quality of the scientific work would suffer greatly as a result. Believing that Koettlitz would be offered the position he wrote:

> In regards to your remark that had I been in England it might have been arranged for me to keep on with the expedition, I doubt whether it could have made any difference. As soon as the essential requirements of the magnetic and meteorological sub committees were disregarded & the geographical work made supreme, there was nothing to justify so long an absence for me. The fact that Koettlitz is good enough for the post shows that the work to be done is completely elementary.
>
> (Gregory, 1901b)

George Murray, editor of the *Antarctic Manual* was appointed acting head of the scientific staff of the expedition on Gregory's recommendation (Yelverton, 2000, p. 56). The memo from Ray Lankester (1847-1929), Director, Natural History Department, British Museum, confirmed Murray's release from museum duties, probably on the expectation of receipt of material for their collections.

> Mr George Murray, F.R.S., Keeper of the Department of Botany, has been invited by the Joint Committee of the National Antarctic Expedition to act as head of the scientific staff of the expedition until the ship "Discovery" reached Melbourne, where

> charge of the scientific staff will be taken over by Professor J. W. Gregory, F.R.S: its regular head.
>
> In view of the fact that much natural history knowledge is expected to result from the expedition, the Trustees have agreed to Mr. Murray accepting the temporary appointment…
>
> (Lankester, 1901)

It is true that Markham considered Koettlitz as understudy to Murray to take over scientific leadership in Melbourne (Markham n.d.d). Murray took the role seriously and raised his concerns about slow progress with preparations, writing to Markham "it's high time somebody did things." Murray also noted his confusion over the appointment process as: "At present it is bewildering. I have Gregory has appointed me; that the Joint Committee has appointed me; and that I may be appointed by the two presidents and the Commander" (Murray, 1901a). Soon afterwards he reported progress with preparation of the scientific gear for work at sea, indicating his belief in his own organisational capability.

> I have spent the last two days in Dundee with Scott, Armitage & Skelton. We have arranged all laboratory fittings and the deck arrangements for windlasses, reels etc. for trawling, dredging, sounding, tow netting and physical work in temperatures etc. We stuck to it and got it done.
>
> I have seen Hodgson, Koettlitz & Shackleton [presumably William] today & on Monday we begin taking stock of the scientific stores ordered and of all that will be needed in that way. They are all inclined to over estimates but I shall see to that. There will soon be order in that department.
>
> (Murray, 1901c)

Arrangements for the scientific leadership had gone awry at an early stage in the relationship between the RS and the RGS, and had not been satisfactorily resolved when the ship embarked.

### 5.1.4 The physicist

Bernacchi had been selected for the *Discovery* expedition on the strength of his polar experience. He never undertook formal university education but learned the arts of astronomy and terrestrial magnetic studies with Pietro Baracchi (1851-1926), government astronomer at the Melbourne observatory in Australia. This was informal, unstructured learning carried out between 1896 and 1898. In a letter of reference Baracchi describes Louis' traineeship thus:

> Louis Charles Bernacchi had frequented the observatory for the last 24 months, during which time he has acquired practical knowledge in, 1st Sextant work for the determination of geographical position, 2nd The making of magnetic observations with a magnetic theodolite and dip circle (Kew pattern), 3rd The general routine of Meteorological observations. He has some preliminary practice in Meridian observations with a portable Transit Instrument, and other miscellaneous astronomical work.
>
> (Baracchi, 1898)

Bernacchi's father Diego, who knew Baracchi socially, brokered the arrangement (Crawford, 1998, p. 21). Bernacchi was to have joined the *Belgica* expedition (1897-1899) of Adrien de Gerlache (1866-1934) in Melbourne, but the itinerary changed when the vessel became ice-bound, so the re-supply, and Bernacchi's involvement never eventuated. That opened the door for Bernacchi to join Borchgrevink's *Southern Cross* (1898–1900) expedition on which he spent a full year on the Antarctic continent as physicist and meteorological observer (Bernacchi, 1901a). He recorded an extensive set of magnetic data in rudimentary conditions. After the *Southern Cross* expedition he delivered a paper to the RGS in July 1900 on the topography of South Victoria Land and was awarded the prestigious Cuthbert-Peek grant and fellowship of the society (Bernacchi, 1901b). Markham had noticed Bernacchi during the 25 June 1900 presentation to the RGS by Borchgrevink on results of his *Southern Cross* expedition. He wrote to Scott: "There is a very intelligent young man named Bernacchi who had charge of the magnetism, meteorology and photography under Borchgrevink. You should also make a point of seeing him. He will be here for some months" (Markham, 1900d).

The minute book of the Magnetic sub-committee records no involvement in selection of the physicist, and on the few occasions that it met, the business was concerned with the ship and instrumental arrangements at a superficial level. Creak, as chairman of that committee, wrote an official note to the Joint Executive Committee on 7 May 1900, stating the case for a civilian magnetic observer in addition to the officers with magnetic observing skill.

> I write to inform you of a resolution unanimously adopted at the last meeting of the Magnetic Sub-Committee.
>
> 'That the Civilian Staff should include a trained observer for Magnetic and Meteorological work.'
>
> I should explain that the object of this resolution is to provide an observer when the Naval Officers are necessarily absent on Executive duties and especially for the magnetic and meteorological work at the Southern land station.
>
> (British National Antarctic Expedition, 1899)

Bernacchi's appointment was preceded by numerous false starts in the recruitment. Markham disregarded Gregory's initial nomination of "Professor Miers" (presumably Henry Miers, 1858-1942) in the first instance. After this, the Joint Committee agreed at its 15 June 1900 meeting to recommend James Pollock (1865-1922), Professor of Physics at Sydney University but Pollock's request for leave for the duration of the expedition was declined (Yelverton, 2000, p. 54). George Simpson (1878-1965) was eventually recruited as physicist around Christmas 1900, but he was unfit and failed the medical test (Admiralty, 4 June 1901). Simpson later became the meteorologist on the *Terra Nova* expedition and his scientific achievements led to directorship of the Meteorological Office in London. Simpson's replacement was William Shackleton (1871-1921) from the Solar Physics laboratory. Shackleton had expedition experience including one polar excursion in 1896 when he travelled with Sir George Baden Powell (1847–1898) to "Novaya Zembla" to view a solar eclipse, where he captured the first solar corona and chromospheric spectra photographs (Royal Astronomical Society, 1922). He was appointed on 30 January 1901, then dismissed shortly before the expedition embarked on the pretext of dental problems and with a payout of £50. He had argued with two of the officers about stowage of stores in the hold in the vicinity of the magnetic observatory and had made himself "objectionable" by disagreeing with Markham's view of the role of the civilian scientific director (Baughman, 1999, p. 54; Shackleton [W] 1901a).

Bernacchi was working for the RS on the results of the *Southern Cross* and writing his narrative of the expedition *To The South Polar Regions* (Bernacchi, 1901) when he was recruited to the *Discovery* at the last minute in late July 1901. He only accepted the position on 27 July after clarifying that Shackleton's position was irreversible (Yelverton, 2000, p. 65). Shackleton wrote of his concern about Bernacchi's lack of opportunity to become familiar with the instruments for the expedition: "I had a wire from Mr Murray this morning informing me that the post had been offered to Mr Bernacchi…" then "Mr Bernacchi & I have been pretty friendly + the ordinary magnetic work will be in good hands, but I don't see how he can possibly manipulate the Eschenhagen instruments without instruction, also the seismograph + sea–water work which I had undertaken" (Shackleton [W] 1901b).

Bernacchi was experienced with the standard magnetic instruments but needed training and practice in the use of the new instruments, the Lloyd-Creak dip circle and the Eschenhagen magnetometer. Bernacchi was told to report to the National Physical laboratory (known as the Kew Observatory prior to 1 January 1900) for training in use of the German instrument on 15 August, but it had been delivered without the instructions. This precipitated a lightning trip to Potsdam to meet Professor Max Eschenhagen (1858-1901) and learn the operations of his magnetometer. Bernacchi then returned to continue training and calibrating the instruments at Kew. To rectify his ignorance of seismology he also visited Professor John Milne (1850-1913), inventor of the seismograph, at his home and observatory on the Isle of Wight (Image 3).


Image 3: Left to Right, Louis Bernacchi, unidentified gent and Prof. Milne, with Mrs Milne seated at rear. Photographed at Milne's residence and seismic observatory at Shide, on the Isle of Wight, 1901 (Rucker collection of Bernacchi family materials).

Bernacchi was still in training when the *Discovery* embarked on 6 August 1901 so he stayed behind, and later joined the mail steamer *Cuzco* to catch the *Discovery* in Melbourne (Bernacchi, 1938, p. 4).

There was a great contrast in the academic backgrounds of the physicists for the *Discovery* and *Gauss* expeditions although the work was the same. Bidlingmaier's scholarship prepared him perfectly for polar magnetic work with its combination of practical and theoretical background (Vanhöffen, 1915). He commenced work for Drygalski's expedition in May 1900, soon after completing his PhD dissertation then continued his preparation for research in terrestrial magnetism over the next fifteen months at Potsdam observatory (52° 23' N, 13° 04' E).

### 5.1.5 Civilian scientists

Recruitment to positions on the civilian scientific staff was not through advertisement or expressions of interest. The process was opaque and mostly based on personal recommendations from senior figures in the expedition management. Unlike the German expedition, the *Discovery's* scientific staff were not doctoral scholars. They were recruited under pressure from sponsors or by personal recommendation. The sub committees for each scientific discipline had little influence in the selection process and the civilian scientific staff for *Discovery* was small.

Koettlitz was the only member of the civilian scientific staff aside from Bernacchi with any prior polar experience. He had been a member of the Arctic expedition to Franz Josef Land. Having Harmsworth, one of the *Discovery* expedition's major sponsors, as a referee did not disadvantage Koettlitz. Markham wrote to Gregory seeking his approval to appoint Koettlitz and proposing Bruce as "Chief Assistant" at the same time (Markham, 1900a). Gregory agreed to Koettlitz in April and he was appointed on 26 May 1900. Aside from his duties as surgeon he was responsible for botany, bacteriology and had a keen interested in geology (Jones, 2011, p. 126). Koettlitz prepared for the expedition by working at the BMNH "on the scientific aspects of phytoplankton" with Murray, and in the bacteriology department of Guy's Hospital (Jones, 2011, p. 126). He also took on the task of procuring various scientific instruments and items of medical kit.

Wilson had a BA degree from Cambridge, having read the Natural Science Tripos and was a qualified doctor of medicine, but had never practiced after completing his M.B. (Savours, 1966, pp. 13-14). He was also an amateur naturalist and wildlife artist. He was assisting with analysis of zoological specimens from Borchgrevink's *Southern Cross* expedition at the BMNH when his influential uncle, Major General Sir Charles Wilson (1836-1905) and Philip Sclater (1829-1913), president of the Zoological Society both recommended him to Markham (Baughman, 1999, p. 34). Markham wrote to Scott, "I enclose a letter from General Sir Charles Wilson about his nephew who wants to go as Second Surgeon. Poulton has seen him and likes him as regards scientific attainments. I told Sir Charles to tell him to write to you" (Markham, 1900c). Wilson's medical examination was delayed as he had an abscess related to blood poisoning, but when finally examined, was found by the Admiralty medical officer to be unfit due to disease (tuberculosis) in the right lung (Admiralty Medical Board, 1901). Scott disregarded this matter and allowed Wilson to join the expedition after he offered to go on his own responsibility (Baughman, 1999, p. 34).

Hodgson was recommended to the expedition by Gregory on the basis of his experience in which he had "done a good deal of dredging in the channel" and had studied lower crustacea "on which he has published" (Gregory, 1900a). Hodgson had worked in a minor position at the Plymouth Biological Laboratory and as a curator of the Plymouth Museum, from where he was recruited to the *Discovery* (Yelverton, 2000, p. 52).

Ferrar was twenty-two when he completed his honours degree at Sidney Sussex College in Cambridge in the Natural Science Tripos in June 1901. He was recruited to the *Discovery* expedition after meeting Markham for luncheon on 21 July 1901. He sailed with the ship in early August, just three weeks after his recruitment (Yelverton, 2000, p. 62; Scott, 1905b, Volume 1, p. 70). Gregory had urged that appointments should be made as soon as possible so that members could get study time on their particular subjects and "gain experience in ice work and on ski in Switzerland during the coming summer" (Gregory, 1900a).

### 5.1.6 Officers

Appointment of the officers also hinged on personal recommendations and favouritism. The officers for the expedition were a mix of RN and Merchant Navy men. Markham would have preferred an all RN wardroom but Harmsworth, a significant benefactor, made his donation conditional on the acceptance of Albert Armitage (1864-1943) and Koettlitz. The Admiralty was not generous with the provision of officers, although they were considered to be on duty during their polar service, thus ensuring they did not lose promotion priority. Correspondence from the Admiralty implies that their wages were compensated from the expedition funds (Macgregor, 1903).

Lieutenant Armitage, RNR was, like Koettlitz, a veteran of the Jackson-Harmsworth expedition. He was recruited in May 1900 and commenced service with the expedition in January 1901 as navigator, icemaster and second in command. His background included considerable polar experience and four round trips to India under sail (Walton, 1984, p. xxiii). As part of Markham's strategy to maintain a line of command in keeping with RN protocols, Armitage became a lieutenant in the Royal Naval Reserve in February 1901. His scientific contribution was in the magnetic science research, mainly at sea.

Ernest Shackleton was the other member of the wardroom from the merchant service. He had extensive experience in square-rigged ships and gained his master mariner's certificate in 1898 (Baughman, 1999, p. 32). Like Armitage, he was commissioned into the Royal Naval Reserve, as a sub-lieutenant prior to departure. He had become acquainted with the son of the major benefactor of the expedition, Longstaff, during a troop ship voyage to South Africa. He used that relationship as a lever and joined the crew in mid February 1901. He was "the only officer appointed without an interview" (Yelverton, 2000, p. 58). His experience indicated his suitability for the position, but Scott charged Armitage with the task of checking Shackleton's background (Huntford, 1985, p. 29). Shackleton's scientific role was to measure seawater density and salinity, and he received training from Mill in these arts (Baughman, 1999, p. 67). He also took on observations of the characteristics of waves in the open ocean (Markham & Holland, 1986, p. 80). Shackleton's formal training was one day with the Royal Engineers in Aldershot (25 July 1901) where he, Skelton and one of the stokers learned to operate captive balloons, as the expedition was to be equipped with two (Yelverton, 2000, p. 60). He also spent a short time testing detonators that may have been called into service to free the ship from ice (Huntford, 1985, p. 39).

Lieutenant George Mulock (1882-1963) of the relief ship *Morning* replaced Shackleton when he was repatriated on the relief ship *Morning* in 1903. Mulock was one of many applicants for a position on the relief ship. Markham knew Mulock's family, and although this may have swayed Markham in favour of his selection, he became a great asset to the expedition, being a talented surveyor and cartographer (Baughman, 1999, p. 201; Scott, 1905b, Volume 1, pp. 71-72).

Charles Royds had achieved the rank of lieutenant in the RN in 1898 (Scott, 1905b, Volume 1, p. 67). Again, Markham had a personal connection, having travelled on the outward leg of the North Polar Expedition (1875) with Charles' uncle, Commander Wyatt Rawson (1853-1882) (Caswell, 1977). Royds volunteered to serve on *Discovery* on 3 April 1899 and Markham requested his services from the Admiralty. His appointment was confirmed on 6 June 1900. Royds was First Lieutenant of *Discovery,* and charged with responsibility for meteorological observations (at sea and ashore) and was intended as an understudy to assist with magnetic observations. After the compass magnetics course with Scott (September 1900) Royds travelled to Scotland to train in meteorological techniques in winter conditions at the observing station on the summit of Ben Nevis. He remained there until February 1901, then went directly to Kew Observatory for a course in procedures for magnetic observing using some of the sophisticated instruments that would be available to the expedition (Yelverton, 2000, p. 53).

Two of Scott's former shipmates were appointed to *Discovery*. Markham negotiated Michael Barne's (1877-1961) release from the Admiralty and the Joint Committee appointed him second lieutenant in June 1900. Barne was "Scott's special choice" from the *Majestic*

(Bernacchi, 1938, p. 216). His scientific responsibilities were deep-sea sounding and support for Armitage in magnetic research at sea (Savours, 2001, p. 21). Barne also attended training at the Ben Nevis observatory during February 1901 before attending the compass course at Deptford (Yelverton, 2000, p. 58). Reginald Skelton joined the *Discovery* as her engineer, and qualified for his engineer's certificate in 1901. Skelton's release from regular naval duty came in September 1900, allowing his involvement in construction of the *Discovery* in Dundee. Skelton's oversight of the installation of the engineering hardware of the ship was invaluable at a time when Scott was overloaded with responsibilities (Skelton, 2004, p. 8). Skelton supported Bernacchi's physical science research on numerous occasions by assisting with construction and repair of apparatus and by taking observations from time to time. Scott also charged Skelton with duties as official photographer to the expedition (Skelton, 2004, p. 9). The Admiralty confirmed the appointments of Scott, Royds, Barne and Skelton to the expedition commencing in July 1901 by letter to the Presidents of RS and RGS (Macgregor, 1901).

Not all personal recommendations bore fruit. Creak, who had contributed to the magnetic reports for the *Challenger* expedition, also proposed a RN officer as a candidate for the magnetic research, but his recommendation was not acted upon, possibly as a result of Markham's strong prejudice against recruits from the survey branch of the Admiralty.

> I would strongly recommend Commander Jas. W Combe R. N. as a valuable officer for Antarctic exploration. He is an experienced officer in the use of magnetic instruments both on land and on board ship & an excellent observer. In addition to this as an experienced hydrographic surveyor he is now serving in his third command. He is physically strong & energetic & has been most zealous in making magnetic observations.
>
> (Creak, n.d.a)

The magnetic training received by the *Discovery's* officers intended to support the work of the civilian physicist was inadequate. The magnetic expert Chree, of the National

Physical Laboratory (previously Kew Observatory, and generally referred to as such in correspondence), wrote to the secretary to the *Discovery* expedition, explaining that a fee for training the officers in the use of magnetic instruments was enclosed but that “As regards the instruction, the fees have been reduced, partly owing to the comparatively small time some of the officers have attended” and “Other of the instruments sent were apparently intended only to afford members of the Expedition an opportunity of learning their use, an opportunity which has I think been somewhat imperfectly utilised” (Chree, 1901). Richard Glazebrook (1854-1935), director of the Laboratory, shared Chree’s concern over inadequate attendance at the training. In a further letter to Cyril Longhurst (1878-1948), secretary to the expedition, he explained that the 15 guineas for instruction of the officers “represents a considerable reduction from the charge usually made to Naval Officers for a course of instruction” (Glazebrook, 1901). Scott and the other officers (Royds, Armitage and Barne) went to the Deptford Compass Depot for training with Creak, in addition to their course of study at National Physical Laboratory in Kew, under Glazebrook (Yelverton 2000, p. 354). This was about magnetic work related to navigational aspects of the expedition rather than the terrestrial magnetic research. Markham’s close interest in the selection of the Executive Officers and civilian scientists is indicated by his record of biographic details of each, including drinking habits of most, as shown at Table 4, below (Markham, n.d.c).

| Name | Participation |
|---|---|
| Barne | One glass of spirits per day |
| Shackleton [W] | Do not take either wines or spirits except dinner claret |
| Wilson | None, unless required as medicine for a short period |
| Koettlitz | Small quantity of Whiskey once daily |
| Hodgson | Rarely drink |
| Skelton | Very moderate consumption-no particular choice |
| Royds | Can drink anything, Port, Claret, Whiskey + beer being the most usual of my beverages, also burgundy at times. |

Table 4: Average Consumption of Alcoholic Beverages by wardroom (Markham, n.d.c).

### 5.1.7 Information gathering

Markham was alert to the value of specialist advice during the critical months of preparations and while grooming Scott for the leadership. It was his habit to take summer holidays in Norway and on 11 July 1900, soon after Scott had commenced work, Markham wrote advising that Dr Johan Hjort (1869-1948) who he described as Head of Fisheries “here” [Norway] was in charge of a vessel, the *Michael Sars*, especially built for research between Norway and Iceland. Hjort was actually director of the University of Jena Biological Station in Drøbak at that time (Hardy, 1950). *Michael Sars* was equipped with modern deep sea trawling and sounding gear. Markham knew that Drygalski was taking a cruise with Hjort in September and that it was crucial that Scott should visit when the ship returned.

> A hundred little things will occur to you in examining all the arrangements and fittings and the various instruments and gear. You can get full information about Nansen’s electric light installation, cooking apparatus, his views on the best form of sledge etc; and will be glad to see you about anything else you may think to get in Norway.
>
> (Markham, 1900e)

Markham also suggested to William Wharton, Admiralty Hydrographer (1843-1905) that “It will be very desirable that the Antarctic ship should be supplied with the latest & best of everything as regards appliances for scientific investigation” (Markham, 1900f). He later described the successful demonstrations of the sounding and trawling apparatus, and wrote that Hjort could help supply equipment such as nets, dredges, Pettersson water sampling bottles and that “An instrument for ascertaining gases in salt water and salinity by chlorine test must be supplied; and Scott can get it from Knudsen in Copenhagen” (Markham, 1900g). At the same time the famous polar explorer, Nansen, was friendly towards the expedition through correspondence and advice to Koettlitz. In June 1896 Nansen had been returning from his North Pole bid and, by chance, found the Jackson-Harmsworth Arctic expedition of which Koettlitz was a member in Franz Josef Land. They became firm friends. “By November [1900] Koettlitz was asking Nansen’s advice on sourcing additional equipment - sledges, ski, sleeping bags, gloves, footwear, in particular the reindeer fur boots called finesko” (Jones, 2011, p. 122).

There were positive outcomes from Scott’s visit to Scandinavia and Germany. First was the acquisition of knowledge and recommendations regarding polar techniques and equipment, especially “furs, skis, sledges and cookers, the latter two of Nansen’s own design” (Baughman, 1999, p. 53). The second was the realisation there were many matters still to arrange and that Drygalski’s expedition was much further advanced in recruitment, training and preparations. Scott later acknowledged Drygalski’s kind welcome and freely given assistance.

> In Berlin I found the work of equipment in full swing: provisions and stores had already been ordered, clothing had been tried, special instruments were being prepared, the staff of the expedition had been appointed and was already at work, and the ‘Gauss’ was well on towards completion. I was forced to realise that this was all in marked contrast with the state of things in England, and I hastened home in considerable alarm.
>
> I found, as I had expected, that all arrangements which were being so busily pushed forward in Germany were practically at a standstill in England; many of them, in fact, had not yet been considered.
>
> (Scott, 1905b, Volume 1, p. 33)

Murray was also concerned. He confided in Markham about his own correspondence with Poulton of the RS:

> I have written to him very plainly indeed stating I find the scientific preparations in a very backward condition and that there must be less disputing in the future. I know Poulton and how to deal with him. He makes me swear but the best way is to do it in his presence!
>
> (Murray, 1901b)

There are notable omissions from the scientific staff of the expedition. Although they were destined to a land they knew was ice covered and where there was sea ice for most of the year, they took no ice specialist. Also, knowing that the expedition would most likely overwinter in the deep south, there would have been opportunities for an astronomer to view regions of the winter night sky never before studied in any detail. Bernacchi had some training in astronomy but his other responsibilities as physicist aside from magnetic studies (including auroral observation, atmospheric electricity, pendulum experiments for determination of a value for gravity, seismology, solar eclipse observations and calibrating timepieces by observations of occultations) scarcely allowed opportunity for additional duties.

Gregory had suggested Swiss alpinists on the assumption that overland journeys would require experienced ice and snow travellers, not to mention the utility of alpine climbing skills. Armitage took the place of Gregory's proposed Dundee whaling ice master. The history of the expedition showed there was little call for this specialist, although the case has been put that it was only by the skill of such an ice master (Captain Harry McKay [1857-1925]) that the *Discovery* was eventually released from Hut Point in 1904 (Aldridge, 1999). Although they took a number of dogs, there was no experienced dog handler amongst the crew.

Recruitment of the lower deck was by application. Notes on the RN applicants record full name, official number, rate and badges, age and the ship in which they were currently serving. There are no special notes about prior polar or expedition experience, but sailing ship experience, accomplishments in trade, musical, theatrical, sewing, knitting, shoemaking and haberdashery are recorded as the selection criteria (Royal Geographical Society, n.d.).

In summary, the notable features of the recruitment process were 1) a general disregard for relevant polar or field research experience 2) a lack of transparency or systematic processes 3) a disregard of scientific research track record 4) control by Markham over the process 5) nominal involvement by specialist committees 6) factional acrimony between the RS and the RGS and 7) lateness of recruitment. The last factor may not have been especially critical for the geologist, Ferrar, as his preparation was mainly expansion of his knowledge through the reading he undertook that during the voyage to Antarctica (Susanna Ferrar personal communication, 6 September 2012).

The German expedition's sub-committee on meteorology and terrestrial magnetism determined that the magnetic observer should "have at least a year of preliminary practical study, from about 1st April 1900" (Sub-Committee of the [German] Scientific Council for Meteorology and Terrestrial Magnetism, 1899). Bernacchi's recruitment just a fortnight before the *Discovery* departed for Antarctica was insufficient time for even a seasoned scholar, let alone a journeyman, to become familiar with new apparatus and a range of new physical science responsibilities. Training, like recruitment, had been late, and in some cases nominal, but did the enthusiasm and diligence of the scientific staff compensate for those apparent shortcomings?

Chree's comments in his 1908 Physical Society presidential address accurately reflect the lack of organisation that resulted as a consequence of the scientific leadership vacuum created by Gregory's absence in Melbourne, then his resignation during the critical preparation phase. Departure of the expedition commenced to test the quality of recruits, their preparations and training, and their instruments and equipment.

The evidence presented here indicates Markham applied the criteria of youth and family lineage in his talent scouting for officers and scientists, rather than considering the scholarship, experience and research track record of prospective scientific staff. Recruitment for the *Discovery* had no formal governance and as a result it became haphazard and unsystematic. Scientific work on the expedition was planned with scientists and officers acting in the roles of technicians, collectors and observers and following the metropolis/ periphery paradigm of evolving scientific practice at the edges of the British Empire.

## 5.2 England to Cape Town

### 5.2.1 Departure

The outward voyage to New Zealand signified the start of a grand adventure for the young and inexperienced scientists. The expedition departed London Docks on the Thames on 31 July 1901 and moored at Stokes Bay the following evening. This was downriver from Portsmouth and close to the ceremonial departure point of Cowes on the Isle of Wight. It was in Stokes Bay that, in line with common navigational practice and as part of the magnetic science operation, the ship was swung for deviation (error induced by ferrous elements of the vessel) before embarking. The purpose of the operation was to determine the values of compass error indicated (normally at the steering compass, but in this case also at the compass in the observatory) according to the direction of travel. The measurements can be made if the vessel steams in a path describing either an octagon or a rosette so that the variance between the true and indicated headings can be determined on each of the cardinal and intermediate points of the compass. If the ship is moored, the operation may be performed by towing the stern of the ship in a full circle with a whaleboat. A table and a graph are then produced to represent the error according to the direction of travel. These inform watch-by-watch decisions regarding correction to the compass bearing to which the helmsman must adhere. This important procedure was also the first and last scientific operation of the expedition and was carried out from time to time en route. Bernacchi described the procedure. "On 1st August, *Discovery* anchored at Spithead to carry out that most important requirement, swinging the ship-that is, the ship was turned slowly round, whilst errors in her compass at each point were determined" (Bernacchi, 1938, p. 16). The

*Discovery* was relocated on 5 August 1901 to Cowes, where the new monarch King Edward VII and Queen Alexandra inspected the ship and it's scientific equipment. Scott was awarded the MVO (Member of the Royal Victorian Order), presumably in anticipation of outcomes (Skelton, 2004, p. 18).

**5.2.2 Scientific operations and logistics in the Atlantic**

The first leg of the journey to Madeira lasted eight days and the scientific work in some departments commenced immediately the ship put to sea. Armitage's responsibilities for magnetic observations were prescribed in the *Antarctic Manual* and included: "The declination or Variation should, when practicable, be observed twice in the day at sea, and when the sun's altitude is below 30°" and "The dip and force should be observed daily at sea. In the high Southern latitudes the observations should be repeated during the day, the hours between 9 and 11 a.m., and 5 p.m. and 7 p.m., being recommended" (Murray and RGS, 1901, p. 26). At sea, Lloyd-Creak dip circles were used to determine dip and intensity. Declination was calculated on board ship from the vessel's azimuth compass by reference to the apparent bearing of the sun at its noon zenith, in accord with common navigational practice.

Creak developed Lloyd-Creak dip circles from the common Fox dip circles, to allow determination of magnetic force (or intensity) as well as dip (McConnell, 2005). This was achieved by inclusion of Lloyd's needles for intensity, which expanded functionality of the basic unit (Image 4). He wrote to the expedition's Ship Committee (probably in 1899): "I have also a working model of a magnetic instrument for observations of force and dip at sea- utilizing Lloyds method, which I wish to submit to the committee for approval" (Creak, n.d.a). The Admiralty supplied these instruments (Armitage, 1905, p. 302).

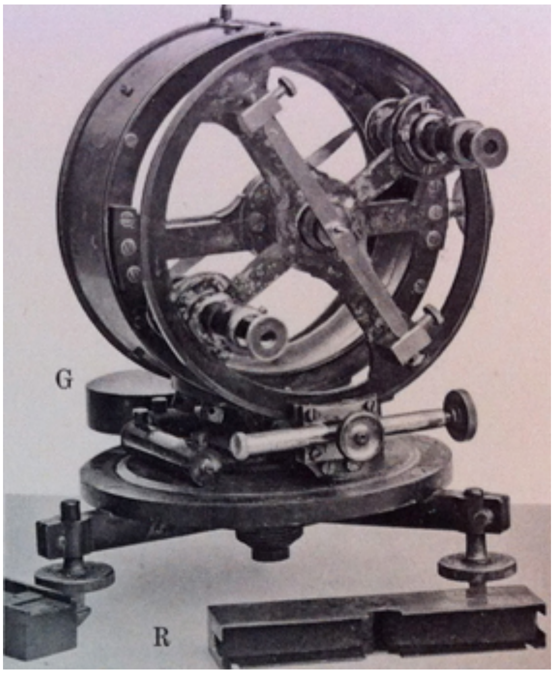


Image 4: Lloyd-Creak Dip Circle used on Drygalski's *Gauss* expedition (Drygalski, 1925, p. 113, Plate II, figure 3b).

Innovations included finer graduations, improved needle mountings and a circular glazed metal case. On the Lloyd-Creak instrument the length of the needle is designed to bring its tip into close proximity to the scale for easy viewing of both at the same time. The *Discovery* and *Gauss* were both issued with these instruments. On the *Discovery* a gimbal stand made of non-magnetic gunmetal was installed in the magnetic observatory, located on the centreline of the ship (the Fox position) and in a manner that allowed the dip circle to be rotated for alignment. *Gauss* had a timber pedestal for this purpose. During observations the dip circle had to be perfectly aligned on the magnetic meridian, stable and horizontal, with the needle coming to rest before an accurate reading could be made. When movement of the ship did not allow the needle to come to rest "a mean of the oscillations on each side of the wire should give good results" (American Geophysical Union, 1901). The "wire" is a cross hair, visible through the microscopic viewfinder that the observer must align with the needle's point. This is achieved by rotating the outer ring of the apparatus that carries the microscopes for viewing both needle and the vernier scale from which the angle of dip is read. These features are shown in detail on a similar instrument, Amundsen's Barrow dip circle (Image 5) used in the locality of the North Magnetic Pole during his *Gjøa* Arctic voyage (1903-1906) although on this instrument a separate eyepiece is used to read the vernier scale. Creak tested the prototype in the observatory, where it performed well, and Glazebrook of the National Physical Laboratory certified the two used on *Discovery* (No.143 and No.149 by Dover, Charlton) as accurate (National Physical Laboratory, 1901). There is no record or evidence of the instrument being tested at sea under normal operating conditions and it's a surprise that both expeditions accepted them without final proof of utility.

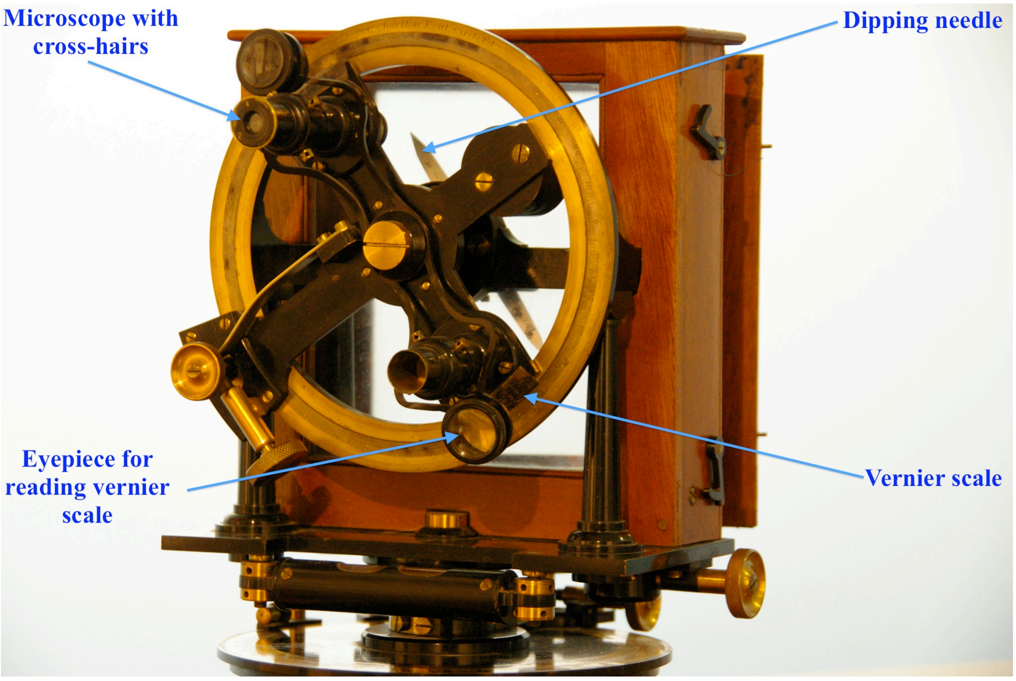


Image 5: Amundsen's Barrow dip circle used in the locality of the North Magnetic Pole during his *Gjøa* Arctic voyage (1903-1906) (author's photo).

The Admiralty was generous with a loan of the standard ship's compass and compensation spheres for the binnacle, but these were for navigation, not the magnetic science research program. The schedule of magnetic instruments supplied by the Admiralty is reproduced at Appendix IV. The conditions of loan were explicit: "I am to add that the compasses, etc. will be lent on the understanding that your committee will pay all expenses of carriage as well as for any loss or depreciation that may occur" (McGregor, 1900). A small but formal booklet entitled “List of Instruments Provided” also lists magnetic instruments for research and navigation. The purpose of this booklet is unclear and it contains full lists of scientific instruments for all the disciplines and its magnetic apparatus schedule is also reproduced at Appendix IV. It is unlikely to be an inventory as serial numbers are routinely used to identify high quality instruments, but none appear in this booklet. It may represent an early wish list, or a list for non-scientists of the equipment in use. In any event, it shows the intention for the magnetician to be well supplied with sufficient and spare tools of trade (List of Instruments Provided, n.d.).

Mill had recently resigned from the position of librarian at the RGS and was able to make arrangements with his new employer, the British Rainfall Association, to travel with the vessel to Madeira in a mentoring role. He was a doctoral scholar with an extensive knowledge of oceanography and meteorology. He had already provided invaluable assistance to the expedition during preparations, had contributed the bibliography for *The Antarctic Manual* and had been a member of the meteorology sub-committee. Four days before departure Scott offered him the opportunity to travel on the expedition’s first leg (Huntford, 1985, p. 45). “He gave daily instruction to those members of the expedition who had charge of the instruments employed to find out the temperature at various depths … Dr Mill, too, as an enthusiastic meteorologist, was of great service to Royds…” (Armitage, 1905, p. 17). Mill reported his activities in two parts, published in the *Geographical Journal,* that combine to provide a picture of active research in the biological and meteorology departments. Shackleton developed skill in the analysis of seawater for density and chlorine content; Ferrar determined atmospheric carbonic acid ($CO_2$), and Royds installed the various meteorological recording instruments at suitable locations around the vessel. Microscopes were mounted securely in the laboratory and collections for inspection were provided by frequent pumping of seawater through a plankton net. Aside from the exclusion of ferrous materials from the vicinity of the magnetic observatory, the magnetic work gets no mention (Mill, 1901; Mill, 1902).

Armitage's own narrative also makes no mention of magnetic work on this first leg in spite of his responsibility for the work (Armitage, 1905, pp. 16-17). Huntford implies that Mill was charged with the responsibility to train up the scientists "from scratch" (Huntford, 1985, p. 45), but Mill notes the care and accuracy with which the work was carried out and, in the case of Royds, he especially notes the considerable experience of the observer. Murray, referred to as the "Scientific Director", personally presided over the biological work of Hodgson and Koettlitz. Wilson's task was to monitor changes in the colours of the seawater (Mill, 1902).

Royds' kept a diary as a record for his family and, of the various narratives and diaries of the expedition, his provides the most candid account of proceedings. While Wilson's diary describes test flights of several box kites during which "two were lost" (Savours, 1966, p. 32), Royds tells us that a school of porpoises took the attention of all on deck away from the task at hand. The result was that two kites dipped into the water unnoticed. Royds also notes here the influence of biological tow nets on the speed of the ship. Although under way with sail and steam, the three nets deployed halved the ship's progress to three knots (Royds, 2001, p. 30). On 14 August the ship was hove to and Barne tested the (Lucas) deep-sea sounding equipment and Garstang dredge. Mill stated: "the result of the trials, which lasted for several hours, was to suggest various improvements in the arrangements" (Mill, 1901). Skelton's diary records an average speed for the trip to Madeira under steam and sail at 6.5 knots, or around 155 miles (250 kilometres) per day (Skelton, 2004, p. 18). Scott's narrative records early concern over the slow progress of the ship after this first leg and therefore the prospect of being unable to practice sounding and trawling operations as preparation for work in Antarctic waters (Scott, 1905b, Volume 1, p. 90).

After a brief interlude in Madeira during which repairs were made to rectify defective ironwork the expedition departed on 16 August bound for Cape Town. The ship's track took them towards the south and west across the North Atlantic, across the equator, then, after approaching the coast of South America, a track to the south-east with following trade winds to the Cape. Although the scientists were settling into routines, the journey was not incident free. On 20 August, against Royds' advice, Scott arranged for a large tow net to be deployed while the ship progressed under sail only. Royds correctly predicted that the fastenings of the net to the frame were inadequate and that the brake on the drum could not control the deployment. Hodgson and Murray were experienced with the operation and also advised against it. The net was lost and the "social barometer was decidedly below par that evening" (Royds, 2001, p. 34).

Soon afterwards, on 23 August, Scott noticed the excessive seawater leakage into the vessel. Skelton had been aware of this since he discovered water entry under the engine bed while the ship was still in the Thames. It was dry docked then to find the cause, but nothing definitive was found and the consensus was that shrinkage of the planks would seal the leaks once at sea (Skelton, 2004, p. 16). Royds also seems to have known of the matter and took some delight in the panic suffered by Scott and Shackleton when the water level in the bilges was discovered. Royds had reported the leak previously but his concerns had been dismissed (Royds, 2001, p. 36). The ingress of water had implications for the magnetic science. In the hold of the ship were tons of tinned foods. William Shackleton's remonstrations about the loading of provisions were surely about the stacking of these below the magnetic observatory. The water leak submerged most of the tinned provisions so they had to be brought on deck and either condemned, or cleaned of rust and filth from the bilge, then oiled. The consequence of shifting the tinned goods was a change in the ship's magnetic signature. Armitage later wrote "those wretched tins made themselves felt, especially after leaving New

Zealand for Victoria Land, when apparently some considerable alteration must have taken place in their stowage" (Armitage, 1905, p. 304).

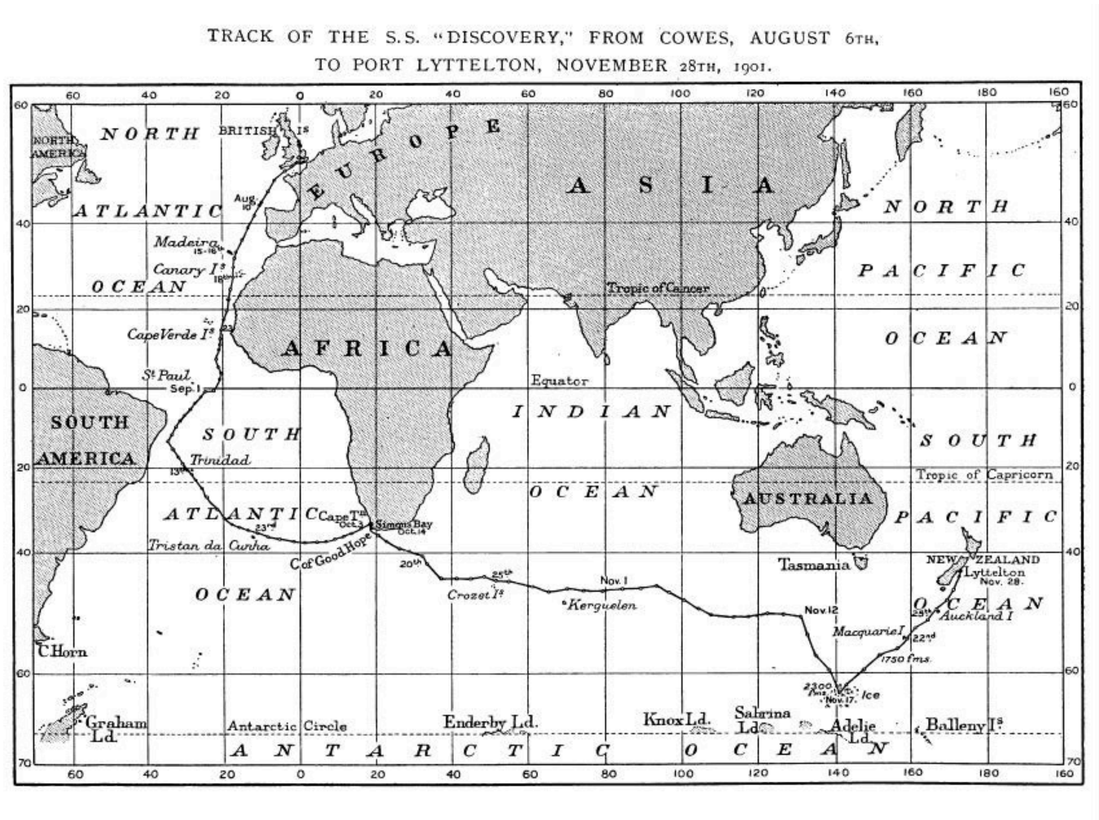


Figure 4: Outbound voyage track of the *Discovery*, England to New Zealand (Murray, 1902).

Following the example of Ross from 17 December 1839, the expedition stopped at South Trinidad Island on 13 September 1901. Previously it had been visited only rarely, but Royds mentions the visit by Ross with *Erebus* or *Terror* (Royds, 2001, pp. 43-45). No magnetic survey was made ashore by the *Discovery*, a decision possibly informed by Ross's experience where he found:

> As a magnetic station, our observations here were utterly valueless, but the results may be useful by pointing out, in a striking manner, the great amount of error to which those made on shore are liable. Three dipping needles placed at only just sufficient distance apart to ensure their not influencing each other, indicated as much as three degrees difference of the dip, and all of them considerably less than that corresponding to the geographical position.
>
> (Ross, 1847, p. 23)

While the expedition members were ashore collecting natural science specimens, Armitage took advantage of the opportunity to again swing the ship for deviation in accordance with the instruction to do so as often as opportunity arose. The magnetic signature of any soft iron in the ship changed as the ship moved through the earth's magnetic field and the physical relocation of the tinned food would have also altered the ship's magnetic deviation. The following table (Table 5) is constructed from pencil notes on the reverse side of one of the magnetic observation record sheets from *Discovery* (Armitage, 1901 a). Although the magnetic observation record is dated 25 September, the data for swinging the ship is undated. It is probable that this is an informal record of the operation at South Trinidad Island. The data and the deviation card derived from it follow.

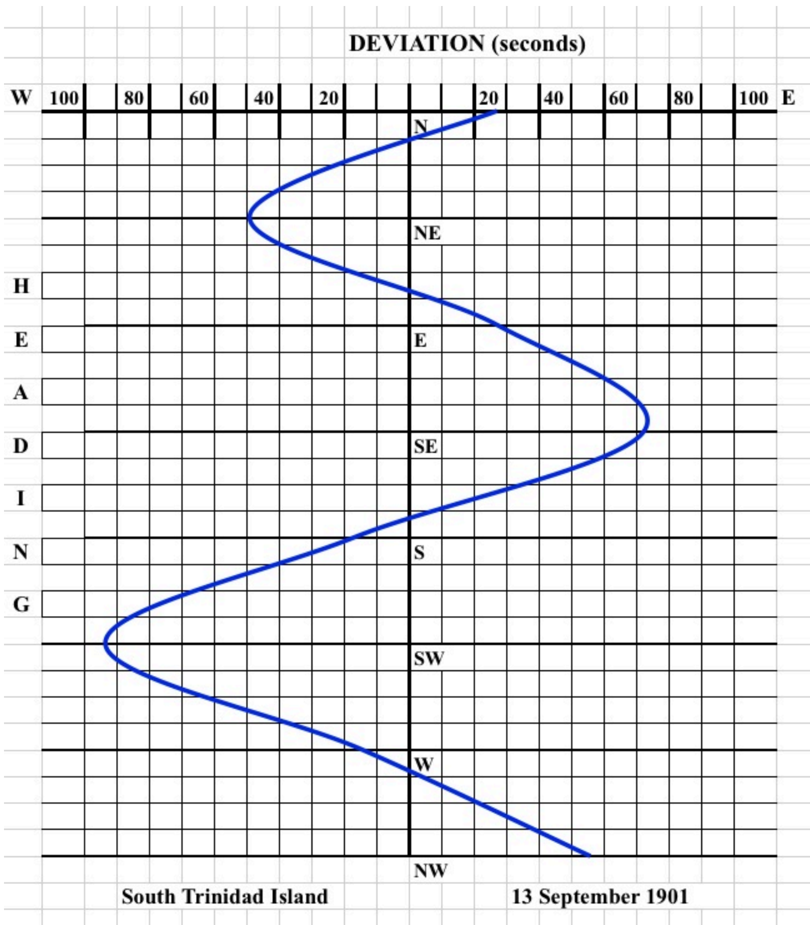


Figure 5: Deviation card from swinging the *Discovery* for compass error, South Trinidad Island.

| True heading | Deviation (Seconds) |
| --- | --- |
| N | 26 |
| NE | -50 |
| E | 26 |
| SE | 71 |
| S | -18 |
| SW | -94 |
| W | -16 |
| NW | 54 |

Table 5: *Discovery's* magnetic deviation swing data, South Trinidad Island (Armitage, 1901a).

Scott does not mention the motivation for making the landing in his narrative but he was already aware they were falling behind schedule. The *Discovery's* schedule was to depart from New Zealand on 4 December (Yelverton, 2000, p. 74). He had decided at Madeira that "Most of the oceanographic work would have to be abandoned" as the ship could not possibly travel the 12,000 miles (19,300 kilometres) to New Zealand in the scheduled 70 days remaining (Yelverton, 2000, p. 75). Each sounding station required the ship to heave-to and lose up to four hours of travel. There was no utility in making magnetic observations at South Trinidad and it was not in the instructions to the expedition to make landings on isolated islands to gather specimens. Scott might have responded to requests from Murray and Wilson to make the landing and collect specimens for the BMNH.

The passage to Cape Town was scientifically uneventful. Scott's narrative deals with the next twenty days in half a paragraph (Scott, 1905b, Volume 1, p. 96). Armitage's account is almost as brief, describing only the birds caught and the weather. He does not mention the magnetic science work but his signed magnetic observation data sheets for days during this period attest to the fact that he was applying considerable time and effort to the task (Armitage, 1901a). The annotations also indicate the ship was rolling through an arc of 60°. Wilson had little medical work and spent most of his days after the landing at South Trinidad skinning and illustrating the bird specimens (Savours, 1966, p. 53). Identification of the abundant southern hemisphere pelagic wanderers (petrels, albatross, prions, shearwaters etc.)

also occupied his time and tow netting still provided work for Hodgson and Murray. On 22 September, a few days out from Cape Town, the crew were informed of the decision to bypass Melbourne and head to Lyttelton, the port adjacent to Christchurch, New Zealand (Royds, 2001, p. 48).

### 5.2.3 Cape Town and Simon's Bay

The stop at Cape Town was always on the schedule for the purpose of calibrating the magnetic instruments (Scott, 1905b, Volume 1, p. 96) and now there were other strong motivations for the visit. Aside from the need to acquire more coal, there were repairs to be made. Twenty tons of water a day was now entering the hull obliging pumping every eight hours, so caulking the seams to compensate for the shrinkage of the unseasoned timbers was necessary (Baughman, 1999, p. 70). The stop provided respite for most of the crew and scientific staff, but not for Armitage and Barne, who had been assisting with the magnetic observations at sea. It meant a shift in the nature of the magnetic work and the instruments being used. After a day's halt at Cape Town for coaling, the ship steamed overnight around the Cape to Simon's Town where the naval facilities were located. A temporary magnetic observatory was established on the rifle range on Red Hill behind the base. While work continued on the ship, Armitage and Barne worked daily in the observatory with the assistance of Professors John Beattie (1866-1946) and John Morrison (1863-1944) and their assistant. Calibrations using the expedition's and the Cape Town Observatory's absolute instruments, the Kew pattern magnetometers, would have taken about a week of normal work (Armitage, 1905, p. 24). The circumstances of the continuing guerrilla war with the Boers meant that use of lamps after dark and away from settlements was unwise so the work took longer. Skelton took three photographs of the tents, and of Barne, Morrison and Beattie at work with the magnetometer. The candidate's visit to Red Hill on 29 September 2011 revealed that Skelton's photographs of the long view of the tent scene at the rifle range (Skelton, 2001, p. 31) were reversed during printing and publication.

Armitage wrote at length in his official report and in a personal letter to Captain Scott during their stay at Cape Town regarding difficulties he was encountering with the Lloyd-Creak dip circle at sea. His letter accompanied submission to Scott of the magnetic observations:

> 1.Variations taken at sea by the standard compass, including the swinging of the ship off South Trinidad Island
> 2. Magnetic Dip & Deflections observed with the Fox circle
> 3. Magnetic Dip at sea with the L.C Circle

Data for magnetic force specified in the instructions and for which the Lloyd-Creak dip circle had been specifically developed, are omitted. Armitage explains it thus:

> The 'Discovery' being very 'lively' even in moderate sea, I find it required a considerable amount of practice to attain that degree of clarity, confidence and accuracy in observing with the Fox and L.C. Circles which is desirable, and hope to much improve on these samples. This is especially the case with the L.C. Circle: due I believe in part, to the greater magnifying powers of the lenses in use with it, so that the needle appears to oscillate in a more erratic manner than of the Fox seen through a lower powered lens… I find that in any sea way it is impossible to use the 'Statical weighted needle' supplied with the L.C. Circle, for it then acts as a pendulum and swings entirely out of the field.
>
> (Armitage, 1901a)

He continued with description of slight damage to the supplied needles and his management of rusted needle pivots. In a separate letter he stated: "it was found impossible to use the Lloyd-Creak Circle" (Armitage, 1901e). The report found its way to Creak who responded that Armitage was lacking experience (Creak, 1901b) but that was not so as Armitage was experienced at polar magnetic work after the Jackson-Harmsworth expedition and, being a navigator, he knew magnetic observing routines at sea. Armitage continued to struggle with the observing on the passage from Cape Town to Lyttelton, where Bernacchi joined the ship.

Bidlingmaier, the physicist on Drygalski's *Gauss* also struggled with the Lloyd-Creak dip circle observations at sea. He overcame the difficulty by replicating the observations many times. "He was not satisfied that he had taken a sufficient number until the mean value was within the margin of error of each observation" (Mawer, 2006, p. 170). The American magnetic expert Bauer later recorded that there were defects in the instruments and that Bidlingmaier had been highly dissatisfied with their performance (Bauer et al, 1917, p. 19). Bauer's obituary of Bidlingmaier states: "Handicapped as he was by lack of certain instrumental appliances … he sought, with splendid success, by theoretical and experimental investigations, to make the contributions to terrestrial magnetism of the German Antarctic Expedition noteworthy ones" (Bauer, 1915). Bernacchi may have also had sufficient theoretical knowledge to enhance the Lloyd-Creak data by similar means. The Carnegie Institution later rectified the shortcomings of the Lloyd-Creak dip circle to make what they called the "Sea dip" that remained in use for the successful voyages of their non-magnetic research vessel, *Carnegie* (Bauer et al, 1917, p. 19). In the magnetic results for Mawson's AAE, Webb wrote "In addition, it is generally accepted by competent observers that a Lloyd-Creak circle tends to give high dips and is a difficult instrument from which to obtain good results under the best conditions." This was in reference to the improved version (Webb & Chree, 1925, p. 55). Repairs to *Discovery* were finished before the magnetic work ashore was completed, and the expedition finally departed the Cape on 15 October, after again swinging the ship for deviation (Armitage, 1905, pp. 22-24).

### 5.2.4 Leadership at sea

There were two layers of leadership on *Discovery*: overall expedition leadership and leadership of the scientific programs. Expedition leadership had been handed to Scott after

Gregory's resignation. Aside from the imperatives in the instructions to the expedition from the Joint Committee, Scott's command was absolute. The *Discovery* was a merchant vessel and the most correct titles of the officers were Scott: Master, Armitage: Mate, and Royds: second mate. These designations were replaced with the RN equivalents (Armitage: Navigator and Royds: First Lieutenant, for example) and the vessel was operated with a strict hierarchy as if it were a RN vessel. Under this arrangement the scientific work of those officers in charge of meteorology, seawater analysis, sounding, dredging and trawling fell under Scott's direct control.

The second layer of leadership was related to the civilian scientific staff. It involved fostering the productive work of the scientific team, maintaining their coherence and allowing the intellectual space for their own inquiry. The official instructions to the scientific leader do not specify how the responsibilities of the role should be acquitted, only that "You will direct the scientific work of the gentlemen who have been appointed to assist you" (British National Antarctic Expedition, 1901). Most of the instructions are concerned with ownership of the collections, observations, records, logs, journals, charts, drawings and photographs. A cooperative relationship with the "Commander of the Expedition" was to be fostered, but there is no doubt where the prerogative sat for decisions about logistics and the use of the vessel for scientific purposes. Successful scientific outcomes at sea relied on frequent monitoring and consultation between the commander and the scientific staff about their activities. An example was the negotiation to have the ship hove-to for sounding and sampling with nets and trawls. For the magnetic program at sea, keeping a steady helm and reducing the ship's roll (if possible) would have greatly assisted the magnetic observations.

There was a scientific leadership vacuum in the initial stages of the expedition. It had commenced when the services of Gregory were no longer required and extended through to the stop at the Cape. Mill provided practical guidance in his areas of skill (meteorology and oceanography) as far as Madeira. The Antarctic historian Baughman sums up the contribution of the stand-in director, Murray thus: “For the most part the scientific staff were concerned with their own branches of inquiry, with Murray giving an occasional bit of direction or advice” (Baughman, 1999, p. 67). Murray originally intended to travel as far as Melbourne but returned to England from Cape Town. It’s important to note that he believed his role had been an extension of the training program, rather than active leadership of research.

> For reasons of haste it would not be possible to stop for deep sea work between Simon’s Bay and Lyttelton, and considering the fact that the training in surface work was complete and there was nothing more to be learnt from my experience, my proceeding to Lyttelton was useless.
> All the deck gear and apparatus was rehearsed and I felt no hesitation in leaving the ship’s company to their duties, so far as my guidance was concerned.
>
> (Murray, 1901f)

Irrespective of the difference in capability of Murray and Mill to provide leadership in their own disciplines during the voyage to the Cape, Armitage and Barne were completely on their own with the magnetic science observations. Murray knew nothing of magnetic observing operations and his capability to demonstrate scientific leadership was limited to his own discipline. He was a botanist who, according to Scott, was only able to inform the work of phytoplankton analysis. Mill’s opinion of the quality of the meteorological data collected by Royds at sea was high:

> Scott sent home the meteorological observations from the Cape. I sent them to Dr Mill who reports that the work done so far has been well done, and he is surprised to find how good it is. He has written his remarks and observations and sent them to Scott. Captain Creak has had the magnetic observations taken during the voyage and at the Cape, and he has also sent his remarks to Scott.
>
> (Markham, 1901c)

The scientific leadership vacuum was not confined to Armitage and his physical observations at sea. Scott expressed his opinion of Murray's capability as a scientific leader candidly to Markham, who then passed it along to Kempe of the RS.

> The return of Murray is a very embarrassing business. In a private letter Scott says- 'Murray leaves us at the Cape … I don't think his best friend could call him a practical man or an organiser, and as director of science on this ship the best that can be said of him is that he has not been in the way… By reputation and his own showing he came with experience in oceanography to teach us the use of our various apparatus. We find that he knows nothing atall about the greater part of it.
>
> (Markham, 1901c)

This opinion about Murray's deficiencies is detailed further in another item of Scott's correspondence:

> To suit his book he must be the Deus ex machine [Latin: god from a machine] of the expedition, which would not be improper if he really had been of practical use to us. But, as a matter of fact, from a practical point of view he was really an impediment. The little he did do would have been better done if he had left it alone. Of three quarters of the scientific work of the expedition he is far more ignorant than I am.
>
> He has absolutely no training or knowledge of the use of instruments with the single exception of the microscope.
>
> (Scott, 1901b)

The first leg was viewed by Mill and Murray as an extension of the training regime but it also served as a settling period for the social climate on board. Mill provided a positive view of Scott's involvement of the scientific work to Madeira. His "Interest in every branch of science pursued on board is of the most practical and personal kind" (Mill, 1901). Then in his subsequent article he states: "The essentially scientific turn of Captain Scott's mind impressed me strongly, and the rapidity with which he mastered the details of oceanographical and meteorological work was remarkable" (Mill, 1902). At sea, Ferrar the geologist was unemployed, Hodgson and Koettlitz were busy with the zoology of the surface waters while Wilson enjoyed the new bird life and preparation of museum specimens. Royds was actively engaged in the meteorological observations while Armitage was engaged in the task of procuring magnetic data from the outset. The next leg of the journey, from the Cape to New Zealand, marked the commencement of the extraordinary operations of the *Discovery* expedition.

## 5.3 New Science: Cape Town to Christchurch

### 5.3.1 Shifting scientific leadership

Murray tried to invest Koettlitz with the scientific leadership before his departure from the Cape, but Scott took over this responsibility for the balance of the expedition (Jones, 2011, p. 134). Murray had interpreted the official instructions to the scientific director, which provided the power to appoint replacement scientists, rather broadly as he had no authority to make the decision to appoint a replacement scientific director. Scott explained his principles of scientific leadership to Markham and detailed the ways in which Murray was an unsuitable choice as director. Although Murray was reported to be a good messmate, he had not provided the intellectual space that fostered research.

> I have now had to take the whole direction of scientific work into my own hands. My principal is to leave each man a maximum amount of freedom in his particular job, and I find it works admirably.
>
> As regards supervision, all that I require is that each individual keeps a summary of his work in my cabin, and writes it up weekly.
>
> These books are open to every one's inspection: so that each man knows at once where to get any information as regards the work of other departments and can correlate his own work when he wishes.
>
> In regard to special work which men wish to do on points of interest that may occur to them, I take opportunities of having quiet talks with them, and they know already that I am always ready to help their work when it is possible.

> I feel that nothing could be more satisfactory than the genuine feeling of loyalty and good comradeship that exists.
>
> (Scott, 1901b)

### 5.3.2 Southern Ocean operations and logistics

The task at hand for the magnetic research at sea in the high southern latitudes had been well defined as early as September 1899. Creak wrote recommendations on behalf of the "Sub Committee on Terrestrial Magnetism, held at the Royal Society, July 14th 1899" that defined the preferred areas of operation for the work at sea:

> 8. The distribution of the places of observation depend largely on the form of the terrestrial is-magnetics, and these are likely to be most complicated in the neighbourhood of the two magnetic foci. Observations at sea are therefore of primary importance in this neighbourhood which is included within the limits given below under (a), (b) and (c).
>
> a) As far South as possible, between the longitudes of 160° W, & 115°E.
> b) Especially in the region comprised between Lat 65°S & 80°S. Long 160°E to 160°W.
> c) Also between 45° S and 60° S & Long 120° to 140° E.
>
> (Creak, 1899)

After the Cape, the next critical destination from Armitage's point of view was defined by Creak's area "c", far to the south of central Australia. This was the region believed to be an area of maximum magnetic intensity, or total force, which does not coincide with the area of maximum dip, the magnetic pole. The ship progressed eastward from the Cape, passing the vicinity of the Kerguelen Islands in late October 1901. The activities of kite flying for meteorology, bird collecting and deep-sea sounding continued intermittently with similar results to the first leg. Kites were again lost on 20 October (Royds, 2001, p. 56) depleting the stock severely, leaving few for later use in high latitudes. *Discovery* had record days travel under sail thanks to the fair winds, but the ship handled poorly in the Southern Ocean in spite of these generally favourable westerly winds. On 28 October a wave "as high as the upper topsail" overtook the ship and flooded the laboratories, including the magnetic laboratory in which Armitage was trying to work (Duncan, 1901). Everything was drenched (including instruments and notebooks) and, although only the small window was open, Armitage had two feet (61 cm) of water in the observatory (Armitage, 1905, p. 20; Yelverton, 2000, p. 86). The record sheets during this time show that Armitage was generally making four sets of observations each day, sometimes five, each taking between three and four hours. Armitage regularly made the observations during the afternoon watch. On 7 November 1901 at Latitude 57° 19' S, Longitude 109° 43' E and using the Lloyd-Creak Circle No 149 with Needle No 1, he clearly annotates the record sheet for dip observations with "Needle constantly out of field of vision" and "Impossible to obtain deflections with this instrument in any sea way" (Armitage, 1901c).

On 12 November the ship met the "radius of greatest magnetic force" and commenced the first magnetic research of any substantive significance. Up until this point all the magnetic observations for declination and all the meteorological observations and wildlife collecting could have been made from any ship on this commonly traversed route. Royds was pleased: "I believe that no one has run down this line [of no variation] before, so that at last we are doing something new" (Royds, p. 64). Scott headed south to make a high latitude for magnetic observations around the predicted area of maximum magnetic intensity at 51° 49'S, 130° 18' E. and Skelton raised steam so the ship could be held as steady as possible during magnetic observations (Skelton, 2004, p. 25). These observations were most likely easier than those at lower latitudes as the ship was amongst pack ice, which subdues wave motion. As the ship was hove-to, Wilson and Skelton were able to shoot birds for the collection that were recovered by the whaleboat (Skelton, 2004, p. 26). Armitage described the conditions in annotations on the observing sheets thus: “Ship hove to in loose pack (sounding) Gentle roll. Moving gradually & steadily through 35° of azimuth’s back, taking 5 to 10 minutes each way” (Armitage, 1901c). Sounding wire and instruments were lost due to kinked wires on 15 November at the edge of the ice pack then on 16 November the ship reached its most southern point for this leg of the journey (62° 50’ S, 139° 40’ E).

In the open ocean, south of Macquarie Island on 20 November they “adjusted compasses at 8pm” (Duncan, 1901). Skelton’s account differs slightly “Raised steam in the early morning, & swung ship for compasses & magnetic work from 6.30 to 8.30, then sounded with Port forward Lucas machine.” He then laments the amount of sounding gear lost in the previous four soundings including 4000 fathoms of sounding wire (about 7,300 metres), “3 or 4 driver tubes, one thermometer & sundries, so we can hardly be said to have been very successful so far with our soundings” (Skelton, 2004, p. 27). Heading north and east towards New Zealand, Scott agreed to the request to stop for more natural history collecting at Macquarie Island (54° 37’ S, 158° 51’ E). Armitage convinced Scott to do so after Wilson offered a bottle of spirits if he succeeded (Savours, 1966, p. 77). In four hours of hunting, the stock of birds for museum preparation was expanded considerably. Ferrar went off on his first serious geologising effort since his graduation.

All of these activities could have been undertaken by less sophisticated vessels with similar results except Armitage’s magnetic research. The shipboard magnetic observatory work was the only unique element of the scientific program and it proved to be the most troublesome. There was no mentor for Armitage to advise on use of the Lloyd-Creak dip when he needed it, and his reports on the difficulties with the instrument were dismissed.

### 5.3.3 Christchurch

In the meantime Bernacchi had been chasing the *Discovery*. He was detained in England by training and practice on the Eschenhagen magnetometer then travelled overland to meet the mail steamer *Cuzco* in Marseilles, bound for Melbourne. Once in Melbourne he had to make arrangements to tranship tons of equipment (including the expedition's pre-fabricated hut, later known as "Gregory Villa", the two magnetic huts, 23 dogs and their food consisting of dog biscuits and dried fish, 30 pairs of Canadian snow shoes and a miscellany of other items) across to Lyttelton (Materials and equipment list, n.d.).

Bernacchi had a near disaster and almost missed his passage to New Zealand, then Antarctica. He was arrested in Melbourne on 13 November, the day of his intended departure. In May 1898 he had purchased shares with a promissory note to the value of £100 but had never acquitted the debt. The Melbourne stockbroking company Ellison and Everard sought Bernacchi's detention and he was booked to sail that afternoon on *Waihora*. The plaintiffs stated that, as the expedition was fraught with danger, Bernacchi might perish and in any event there was little prospect he would return before three years had passed and it was unlikely he would travel via Melbourne (Explorer Arrested for Debt, 1901). Bernacchi must have struck a compromise. He did join the expedition in New Zealand and the RS archives have records of quarterly payments of £62.10/- being made in his favour during 1902 that probably went towards acquitting the debt (Longhurst, 1901b). This is in contrast to other expeditioners who did not receive wages incrementally. The magnetic research program would have been severely compromised if Bernacchi had failed to make such an arrangement.

Bernacchi arrived in Christchurch on 13 November 1901 and immediately started work with the local magnetic specialist, Coleridge Farr (1866-1943), and his assistant, Henry Skey (1877-1947) to establish a new magnetic observatory in the grounds of the current Botanic Gardens (43° 31' 50" S, 172° 37' 18" E) comprised of separate absolute and variation houses fabricated from timber with a slate roof and fixed by brass screws and copper nails (Farr, 1903). The utility for magnetic work at this site was later diminished by the installation of Christchurch's electric tramway. The present hut is a slightly newer structure on the same site and is still used as a site for standardising gravity observations. They had sufficient time to test and compare the expedition's instruments against those of the Christchurch observatory, a necessary part of the instrument calibration routine, but Bernacchi did not set up the expedition's Eschenhagen instrument at this time. The RGS, London, keeps archival holdings of many of the magnetic observation records for variation, dip and total magnetic force for this period which attest to the painstaking nature of the work (Armitage, 1901d). Some examples of the observation records are reproduced at Appendix V.

The experience for the scientific team in Christchurch was similar to their stay in Cape Town. The magnetists had a great deal of work to do while the other scientists were allowed recreation, social outings and easy paced visits to colleagues at the Canterbury Museum to improve local knowledge, especially, in Wilson's case, of southern ocean birds. Even though Melbourne had been bypassed, the arrival in New Zealand on 28 November 1901 meant only a fortnight was available before the revised 12 December departure date. In spite of dry docking in London, then re-caulking at Simon's Town and months at sea during which the seams should have closed up, the water leak was still an issue. Scott arranged for the ship to be dry docked to find and rectify the cause before turning south. Meanwhile, all the stores were removed from the ship and re-tallied, then stowed along with the additional stores brought from Melbourne. Various factors including wormholes, unseasoned timber, incorrectly drilled bolt holes, loose fasteners, overly snug fitting of the steel plates on the bow and a leaking flange were all blamed for the water ingress (Yelverton, 2000, pp. 93-96; Bryan, 2011, p. 151). The leak was still not solved after dry-docking, so the process was repeated. After further work was undertaken, the leak was still as bad as ever but Scott could delay no longer.

The highlights of the passage from England for the scientists had been the unplanned visits to South Trinidad and Macquarie Islands. Neither of these were suggested in the instructions and neither were related to the magnetic science program. The schedule had always been tight if the *Discovery* was to make a timely departure for the Antarctic summer season, and the slow rate of progress of the ship intensified the matter. The outward passage was a joy for Wilson, who observed and, wherever possible collected birds whose detail he recorded in drawings and watercolours but these activities did not require a purpose built polar ship and were peripheral to the core business of the expedition.

The magnetic science program at sea had not been successful. Armitage had struggled throughout with instruments unfit for the task and on a ship that rolled excessively, rather than providing a stable platform. He later stated: "*Discovery* was another word for perpetual motion (Armitage, 1905, p. 303). In addition, the observing schedule was probably impossible to maintain given his prime responsibilities of watch keeping and navigation. Haphazard recruitment processes and Bernacchi's last minute engagement meant he missed a potentially significant contribution to the critical, at-sea magnetic observations on the outward voyage when his theoretical knowledge and experience might have enhanced the value of the observations.

# Chapter 6: Science on the ice and *Discovery's* scientific outputs

Christchurch was a turning point for the expedition. Bernacchi joined the ship and a major shift in the activities of exploration and science was looming. The vessel had not proved satisfactory in many ways and there had already been a number of disappointments in the scientific program. These included the difficulties Armitage had with the magnetic instrument, the loss of meteorological kites, the reduced opportunities for oceanography and the loss of miles of sounding wire with the apparatus, including valuable Pettersson water sampling bottles and specialized thermometers. Departure towards the ice represented a new beginning and the chance to commence substantive new scientific inquiry.

The visit to New Zealand had cost the expedition four weeks (Skelton, 2004, pp. 30-33) and the next destination was Cape Adare, the location of Bernacchi's initial Antarctic encounter during Borchgrevink's *Southern Cross* expedition. This chapter focuses on the scientific practices of the physicist, Bernacchi as a means to demonstrate the operations and challenges of frontier polar science during the era. The stay in Christchurch had provided opportunities for socialising, a little science and preparation of the vessel for the next tests in the Southern Ocean, the ice pack and the Ross Sea. It was crucial that the ship was swung for compass adjustment again. The weather had been cloudy on arrival so, although the magnetic force was measured by the vibration method at that time, no sun sights were possible for accurate determination of true north. This meant that compass adjustment could not be completed at that time (Armitage, 1901d).

The *Discovery* was heavily laden even before the extra supplies from Melbourne were added. As the ship consumed coal at a much faster rate than calculated, and to maximise the opportunity for coastal exploration an additional forty tons of bagged coal were added as deck cargo, along with dogs and sheep. At the last minute an offer of further coal, a gift, was received via the Mayor of Dunedin, so a further twenty-five tons were acquired during an unplanned stop at Port Chalmers near Dunedin. Armitage wrote a last letter to John Scott Keltie (1840-1927) at the RS, posted from there. It reiterated the potential commercial benefits of the *Discovery* magnetic observations as an argument for further fundraising.

> Get more authoritative statement from Capt. Creak if possible, as to the value (to shipping) of the magnetic work done: of the tremendous force about to be placed at Capitalists disposal by the *Discovery* … say it's worth another £10,000 to secure it to Britishers by means of British enterprise backed by British fold.
>
> (Armitage, 1901b)

The body of this chapter concerns the operation of the magnetic research program in Antarctica and the ways in which the outputs were handled and ultimately published.

## 6.1 South to Antarctica

After a relatively smooth passage south, the first iceberg was sighted on 2 January 1902. The ice pack was entered the following day close to the Antarctic Circle and the ship was through the fringe of pack ice quickly, entering the Ross Sea polynya on 8 January. During the time in the ice pack, many seals (including three rare Ross seals) and birds were collected and a number of deep soundings and trawls were also made. Skelton confirmed the value of support by crew to scientific programs when, on 3 January 1902, Hodgson neglected to put sufficient swivels on the dredge, leading to kinked wires: "These scientific people may be alright at looking through a microscope & making theories, but as a rule they are devilish little good at the practical work or catching their specimens." The activity had cost a significant amount of time and Skelton thought that Scott would be "scarcely likely to waste another 6 hours on dredging for nothing" (Skelton, 2004, p. 37).

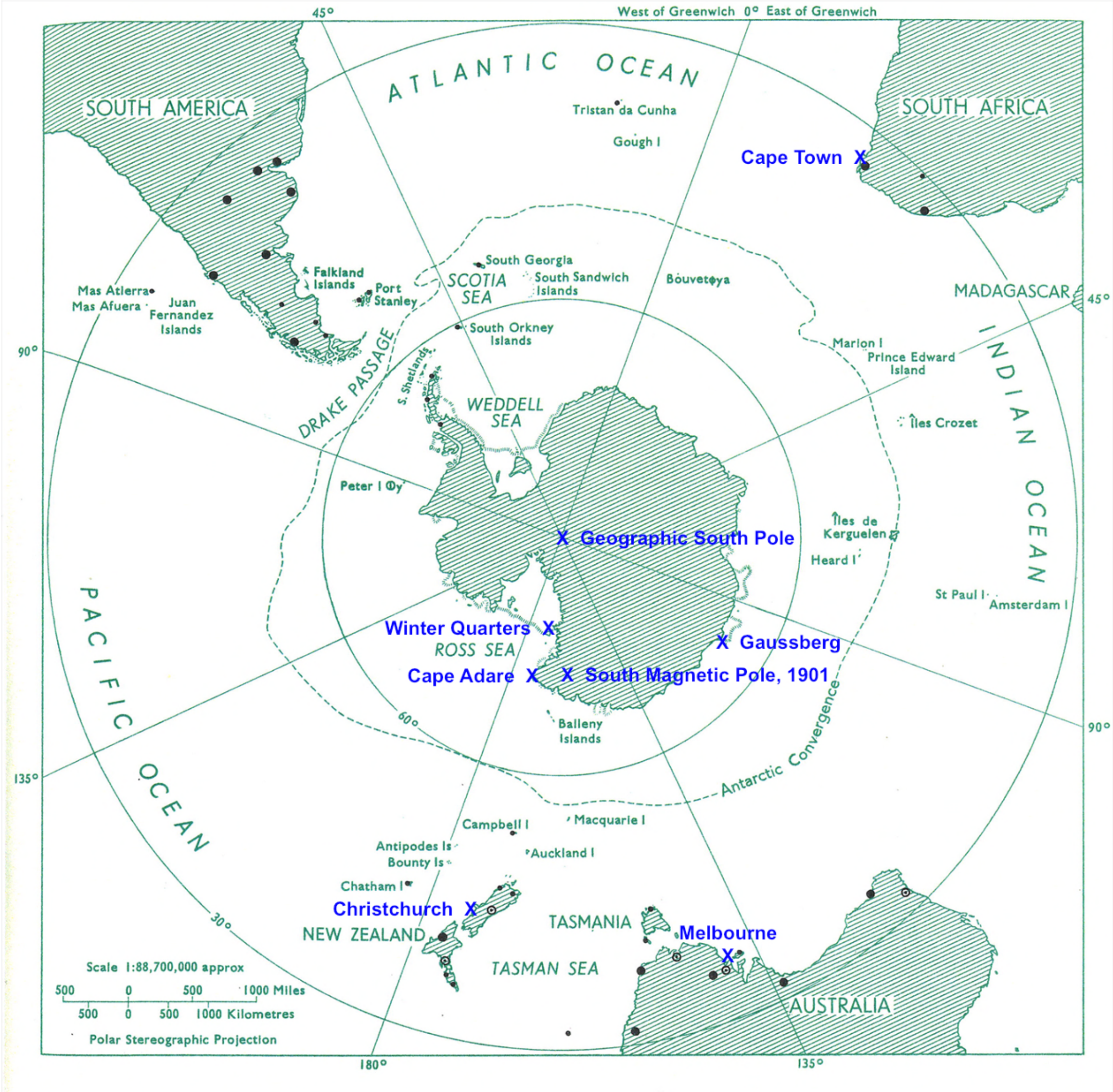


Figure 6: Map locating continental Antarctica and sites mentioned in the text (Base map Priestley, Adie & Robin, 1964).

A landing was made at Cape Adare on the morning of 9 January and the magneticians were first ashore to set up equipment and make observations to determine the amount of change in the magnetic signature of the area since Bernacchi's first visit. "The observations were taken over exactly the same spot as those of 1899, and the values obtained show little sign of secular change" (Bernacchi 1908, p. 132). This work was completed at 10 p.m., after which Bernacchi and some others visited the grave of Nicolai Hanson on the hillside above the cape. Most of the scientists and crew spent time ashore but Hodgson took the opportunity to use one of the ship's whalers to dredge the sea floor for fauna (Skelton, 2004, pp. 40-41).

The next four weeks were utilised for coastal exploration in the Ross Sea. The *Discovery* steamed south from Cape Adare, entering Wood Bay where Bernacchi believed that a suitable landing place with easy access to the interior could be found. Armitage reported the bay to be "almost full of heavy ice" so they returned to clear water where they again "swung ship for compass variation" (Armitage 1905, p. 47). They proceeded to coast Victoria Land as far south as Ross Island, then turned east, following the Ice Barrier where they ultimately discovered new land on 30 January. Scott named it King Edward VII Land, in deference to the expedition's patron.

Scott called a meeting of the wardroom on 2 February 1902 just after they had discovered land and he shared his plans to assemble the huts and overwinter, then make spring journeys to the south and west. The relief ship would coal up *Discovery,* which would then try to connect the unexplored stretch of coastline to the west between Cape North and Adelie Land. "The relief ship would remain behind & land a sledging party near Wood Bay with the object of reaching the magnetic pole" (Royds, 2001, p. 88). This is the only mention of any prospective sledge travel to the magnetic pole. Skelton recalls the same meeting but does not mention the magnetic pole idea, although he does refer to sending a sledge party inland from Wood Bay, an obvious starting point for such a journey due to its proximity to the pole (Skelton, 2004, p. 50). Turning back, the ship halted at an inlet in the barrier and the manned, tethered hydrogen balloon, was sent aloft on 4 February, showing Scott, Antarctica's first aeronaut, that the barrier was extensive and featureless. Bernacchi and Armitage were in the party of six that made a 34 mile (55 kilometres) overnight sledging journey on the barrier to a record 79° S. In spite of their polar experience neither were able to operate the primus stove (Skelton, 2004, p. 53).

It was Scott's decision to keep the ship in the south rather than send a party ashore then retreat to lower latitudes for further exploration and oceanography. This decision was in accord with the final version of "Instructions to the Commander" (British National Antarctic Expedition, 1901). There was no consideration of the alternative plan to drop a land party then proceed with scientific ship work and exploration at lower latitudes over winter (Markham, n.d.e). Nosing south past Ross Island (and again swinging the ship for compass adjustment) they discovered that Ross had been in error naming McMurdo a bay, when in fact it is a strait or sound. Bernacchi recorded the revelation:

> McMurdo Bay as charted by Ross we soon found to be totally wrong. We soon sailed right over the land laid down as the southern extremity of the Bay and discovered that it was not a bay but a strait or channel about 20 miles wide at the narrowest part and beyond.
>
> (Bernacchi 1903b)

The transition from exploration and science at sea to a mostly sedentary polar research base camp meant a massive shift in the roles of most on board the *Discovery*. Oceanography ceased and geology and glaciology began. Meteorology intensified from the shipboard watch-keeping routine to a more complex and comprehensive, but spatially static enterprise. Wilson's work soon switched from collecting and skinning to his secondary role as artist to the expedition as the supply of novel vertebrate life forms became exhausted.

## 6.2 The Hut Point magnetic observatory and scientific practice on the ice

Winter Quarters were located in a sheltered cove at the far south-western tip of Ross Island on 8 February. Within a few days good progress was being made on the erection of the main living hut, whose design was based on Peary's Greenland hut (Gregory, 1906) and the two magnetic observatory huts. These were assembled by affixing asbestos slabs over a wooden frame using non-magnetic (probably brass) screws (Bernacchi, 1908, p. 130). They were 11' (3.35m) square, 9' 8" (3m) high at the front and 7' 4" (2.25m) high at the rear, and cost £100 (Markham, n.d.g). They were ordered from the German company, Calma Co. "at the last moment & were at my suggestion, & my specification, so of course I hope they will prove satisfactory" (Skelton, 2004, pp. 55-58). Bernacchi's imperative was to have the magnetic observatory operational in time for the agreed term day observations on 1 March, so he was taking part in construction of the observatory huts. The ship's carpenter had to finish the construction on 22 February as they "didn't understand the job" (Duncan, 1901). Skelton reported success: "Bernacchi got his Eschenhagen magnetic instruments fixed up in one of the asbestos observation huts today & started it working" (Skelton, 2004, p. 59).

The two magnetic observation huts were located adjacent to the main expedition hut on Hut Point Peninsula. The huts were known as the "absolute" and "variation" huts. Each had a specific function and different instruments were housed within each accordingly. In the variation hut a stable platform was constructed by burying, then freezing in a 24" (61 cm) diameter concrete pipe into the permanently frozen ground, then arranging an oak slab on its top. The component parts of the Eschenhagen magnetometer (*Feinregistriergerät*) were mounted on the slab as shown in Figure 7. On the left, three variometers are illustrated, one for declination and one each for horizontal and vertical force. On the right hand side of the view is the mechanism that contains a drum onto which photosensitive paper is attached. A small lamp on the side of the drum mechanism casts light that was reflected off the polished end or a plane mirror on the end of the magnets in the variometers, the beams then pass through a hemi-cylindrical lens to make traces on the photographic paper on the drum (Royal Society, 1909, p. 75).

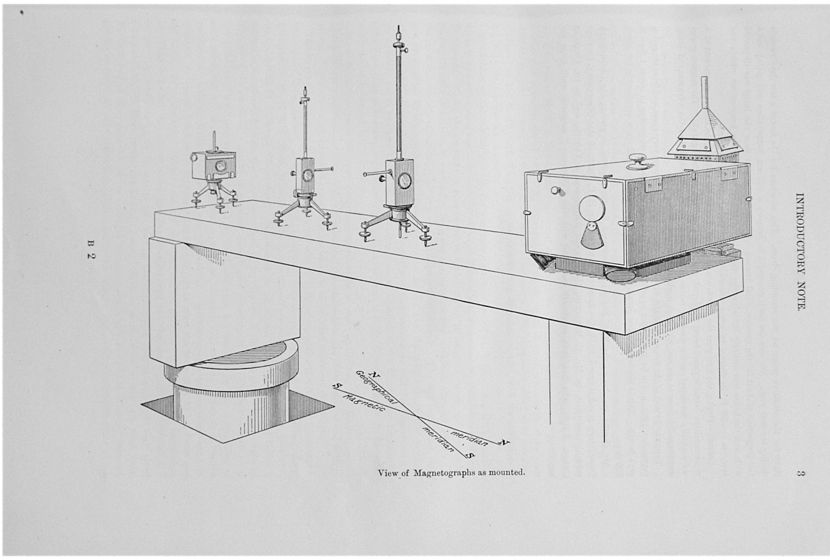


Figure 7: Eschenhagen variometer arrangement in variation hut *Discovery* expedition (Bernacchi, 1909, p. 3).

An important feature of the new instrument was the clockwork drive to the drum carrying the photosensitive recording paper whose speed could be adjusted to vary the sensitivity for the observations, and which otherwise allowed continuous recording (Image 6).

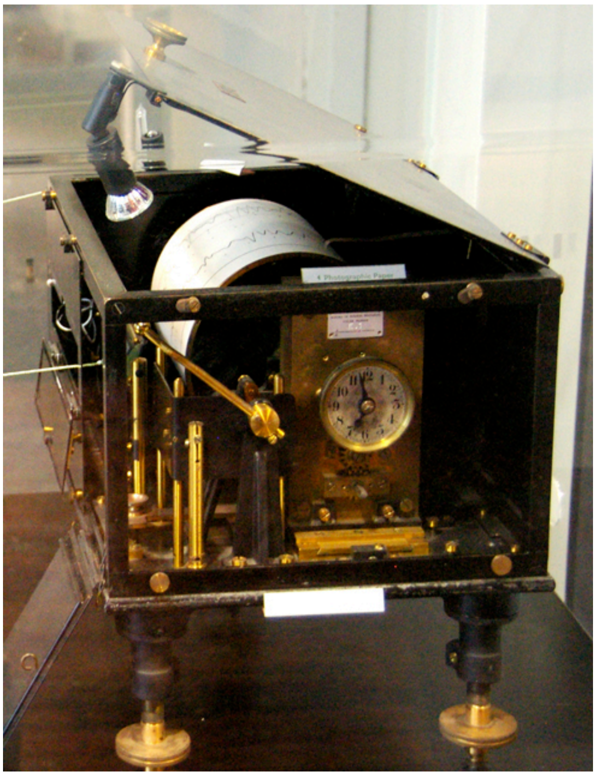

Image 6: Eschenhagen magnetograph clockwork drum, Geoscience Australia, Canberra (author's photo).

This was a recently developed, innovative instrument and copies were also being used on Drygalski's *Gauss*, at his base station on Kerguelen Islands and at the Potsdam magnetic observatory where Professor Max Eschenhagen (1858-1901), the inventor, oversaw the operations.

The absolute hut contained a standard Kew pattern unifilar magnetometer whose purpose was to make "specific measurements of the earth's magnetic field" (Riffenburgh, 2011, p. 126). Those observations of declination and force were the standards against which the Eschenhagen magnetometer results were calibrated. The Kew magnetometer in the absolute hut was situated on a brick pillar for stability (Bernacchi, 1908, p. 130). It consisted of a hollow cylindrical magnet suspended by a fine silk, brass or (in this case) quartz filament that allowed the magnet to rotate freely. In a description of magnetographs at Scott Base, the fibre is described as "so fine that even against a black velvet background it is difficult to see" (Roper, 1983). The end of the magnet carried an etched glass scale that was viewed through a telescopic eyepiece. Image 7 shows the construction of the instrument.

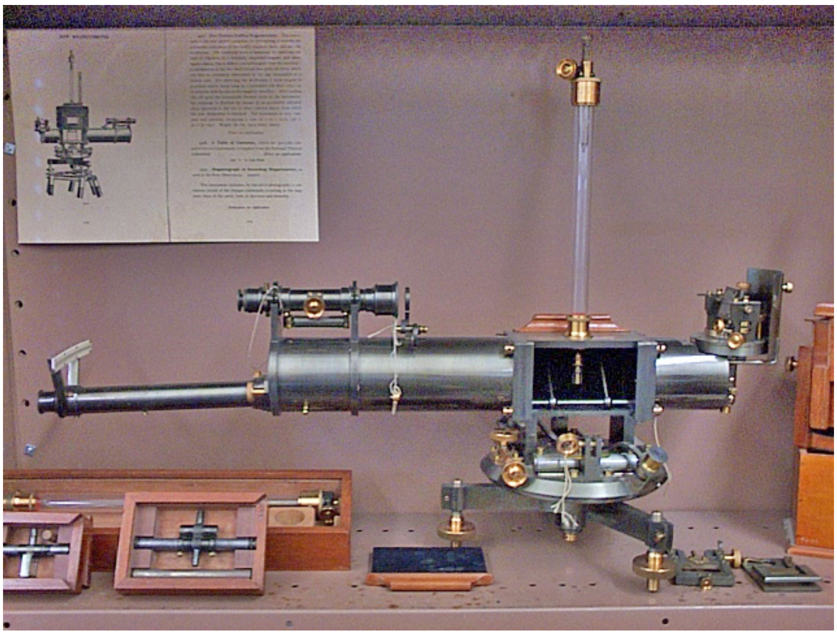

Image 7: Kew pattern unifilar magnetometer, University of Queensland physics museum (author's photo).

Determination of the declination is according to a routine whereby:

> the instrument is rotated about its vertical axis till the centre division of the scale appears to coincide with the vertical cross-wire of the telescope. The two verniers on the azimuth circle having been read, the magnet is then inverted, i.e. turned through 180 about its axis, and the setting is repeated. A second setting with the magnet inverted is generally made, and then another setting with the magnet in its original position. The mean of all the readings of the verniers gives the reading on the azimuth circle corresponding to the magnetic meridian.
>
> (LoveToKnow 1911 Online Encyclopedia, 2004)

Determination of force was a two-step process. Firstly, the period of vibration of the freely suspended magnet in the horizontal plane is determined accurately using an accurately rated chronometer. This gives a value known as the magnetic moment. A deflection experiment is then carried out. The angle by which a secondary magnet is deflected by the magnet used in the first part of the experiment at a known distance is determined. This provides a value for the horizontal component of the magnetic field. These values can be combined to calculate the total of the horizontal component of force. There were various challenges to the operations. Compensations had to be made in the calculations for the torsion of the filament, the inductive effect of the earth's magnetic field, the ambient temperature and the rate of the chronometer (LoveToKnow 1911 Online Encyclopedia, 2004). The geographic meridian must be known with pin-point accuracy. Rather than re-calculate the meridian with each set of observations, it was normal practice to make a visible target on an immovable object outside the hut for alignment. This was a complex operation that could only be performed by an experienced and knowledgeable observer who understood the underpinning theory. Image 8 shows Barne, Beattie and Morrison at work with a Kew pattern magnetometer in the tent observatory on Red Hill, behind Simon's Town, South Africa.

Bernacchi's working conditions were superior to those of many other physicists of the era. Bidlingmaier on the *Gauss* had an observatory on an ice floe constructed from snow blocks. Although an absolute hut was constructed for Mawson's AAE at Commonwealth Bay, the observer was required to stand outside the hut as the magnetometer was accessed through small sliding doors (Riffenburgh, 2011, pp. 126-127). Performing these tasks out of the wind was a luxury for Bernacchi compared to his efforts at Cape Adare using only a tent as an observatory in 1899.

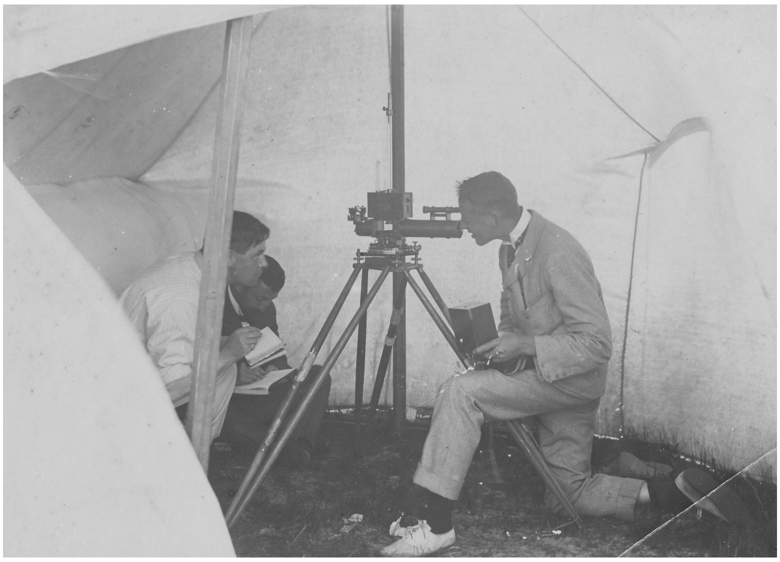

Image 8: Michael Barne operating the Kew magnetometer at Red Hill, Simons Town, South Africa on 11 October, 1901. (RGS negative # B3541). Reproduced with permission (c) Royal Geographical Society (with IBG).

Bernacchi described part of his daily winter routine in his June 1903 diary, by which time he was recording events of a few days at a time in each entry. "Uneventful monotonous days … Took a complete set of absolute measurements on the 28th. Preparations are already being made for the spring sledging." Then the menu for the week is followed by a full description of normal daily routine:

> Rise and stow. At 8am Dr K called to examine the food, milk etc for the men & officers breakfasts … the hunt for ptomaines. Personally I find the greatest difficulty in turning out & am generally one of the latest to breakfast. Perhaps it is because I do not go to sleep until late & perhaps one's blood is in rather a torpid state during the long winter.
>
> (Bernacchi, 1902c)

After breakfast nearly all members of the wardroom indulged in a pipe and read for a half hour before setting about the day's various duties. The men (sailors) had dinner at 1.30 p.m. then were exempt from work in the afternoon. Bernacchi explains in his narrative account that "the magnetic observations were my personal responsibility, and as no one else understood the adjustments of the delicate instruments employed, there was no relief" (Bernacchi 1938, p. 43) but his daily routines were not constrained to magnetic observations, as he also had responsibility for a range of other physical science observations. A set of apparatus for pendulum observations inside an evacuated cylinder, by which the value of gravity and thus the oblate shape of the earth could be determined was supplied for Bernacchi's use. Skelton provided considerable assistance with repairs to get the apparatus to hold its vacuum, then with the actual observations. Bernacchi also had a seismograph for which he had received training from the inventor, Milne. Bernacchi was also to required record features of auroras and he had a set of recording sheets onto which assistant observers (generally the night watchmen) could enter the details of any auroras seen during the polar night. During winter he was often being called in the early hours of the morning by the nightwatchman to observe the auroras. As physicist, another critical duty was to make astronomical observations for precise location of the observatory and to determine the exact time for the calibration of timepieces. One example is on 7 July 1903 when, after opening his diary entry with the usual synopsis of recent weather he states, "Observed successfully with Mulock on Sunday night an occultation of a star ϒ Librae & the moon. It was a good observation & should give a fairly accurate longitude" (Bernacchi, 1902c). Atmospheric electricity measurement and operation of the sunshine recording instrument also fell to Bernacchi, and a spectral camera was used (unsuccessfully) from time to time. On 22 August 1902 Bernacchi noted another attempt at solar spectroscopy with the prismatic camera on first sight of the returning sun marking the end of the long (120 days) polar night (Bernacchi, 1902a). As a consequence of the magnetic science obligations, the lack of an understudy who knew the operation of the Kew and Eschenhagen instruments, and the numerous additional tasks, Bernacchi had little opportunity to travel "off-base." The training of officers at the National Physical Laboratory should have been sufficient for them to take a supporting role in the magnetic observations, but the normal course was only three weeks for officers and those sent from *Discovery* did not attend the full course. None were entirely competent, although Skelton assisted during Bernacchi's sledge journeys.

Once the huts were constructed and the magnetometers established, Bernacchi fell into a cycle of work dominated by the demands of the agreement for synchronous "term day" observations. Daily visits to the variation hut were described by Bernacchi thus:

> The Observatory was entered at between 11 a.m. and noon each day, the light-shutter of the magnetograph closed, and the time of doing so noted by means of a chronometer watch. The thermometer inserted in the Vertical Force instrument was then read.
>
> After changing the paper on the recording cylinder, filling and trimming the lamps, the thermometer was again read, the light-shutter dropped, and the time of doing so noted as before by means of the chronometer. The whole operation occupied about 30 minutes, and times of stopping, starting, temperatures and error of watch on mean time were entered in a note book.
>
> (Bernacchi, 1909, p. 2)

During 1902 Bernacchi tried (unsuccessfully) to keep the hut temperature stable by means of a heating lamp, so this required refuelling daily. On the term days, the first and fifteenth of each month, Bernacchi had to perform sets of fast run observations. During these he adjusted the clockwork drive of the Eschenhagen instrument to rotate the drum at a much faster rate, giving a higher resolution of the changes in the local magnetic elements. The routine also included processing the photosensitive paper magnetograms, then interpreting their traces. With three variometer traces, a base line for each, then a further trace for temperature, there was a total of seven trace lines on each magnetogram, making interpretation a challenge. An example trace from a magnetic disturbance on 3 April 1903 follows (Figure 8) showing the complexity of traces that often became confused with each other and the tendency for traces to go off scale on magnetically disturbed days.

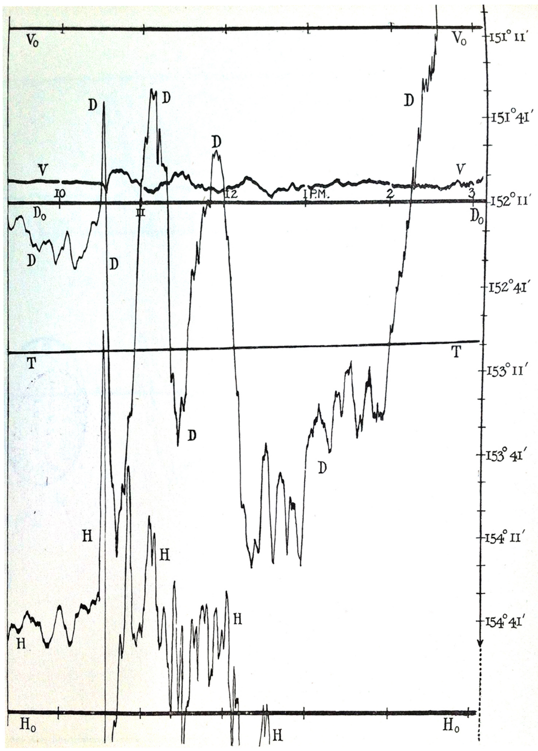


Figure 8: Magnetogram, Winter Quarters, 3 April 1903 (Royal Society, 1909, Plate XXVI, following page 274).

As the weather got colder with approaching winter, Bernacchi found he needed to alter the chemistry of the processing solutions for the magnetograms as the developing time was too slow. He later complained in his diary that the huts provided little insulation against temperature fluctuations, especially during summer. On 1 January 1903 he wrote:

> Have had much trouble of late with magnetic instruments. It is impossible to keep a uniform temperature within the hut & the temp simply fluctuates with the daily outside range. The asbestos huts are very ill adapted for this purpose. They are more like ovens inside. Inside the living hut where the seismograph is now placed the temperature is much more uniform, but then there is another difficulty from water continually drips down upon the instruments due to the snow melting which has accumulated between the roof & the lining or ceiling.
>
> (Bernacchi, 1902c)

Within three months Bernacchi reported the hut becoming too cold. On 21 March he noted the temperature within hut was very low and handling instruments was a “cold business”. From 23 to 25 March 1903 a snow wall was constructed around the variation hut. “Have built up snow wall 2ft 3in [68 centimetres] thickness well above the roof + also covered over roof so may be able to keep something approaching a uniform temperature within. All instruments working satisfactorily” (Bernacchi, 1902c). He still wrote long entries throughout the second winter in comparison to many other diarists that abridged or neglected their entries in the second year as there seemed to be little novel activity. Bernacchi went into the details of daily life routines at one stage and continued to comment on the scientific work and its difficulties, and offered some ideas about the meaning of results. He did not mention much about the social landscapes or his personal relationships.

Neither the physical structure of the huts, or the construction techniques appear to have been to the highest standard. Bernacchi reports an accident within the variation hut that caused a break in the record in mid January of 1903:

> Had a very unfortunate accident within the magnetic hut during the night of the 16th. On entering on morning of 17th found that one of the asbestos slabs had fallen from the roof upon the instruments. I thought at first that they must be completely demolished but on examination found that only two thermometers had been broken & quartz fibre of H instrument. The slab had entirely missed the declination instrument & record had continued without interruption, [illegible] the baseline magnet being thrown out of adjustment. Had the instrument under way again on the 19th.
>
> (Bernacchi, 1902c)

Regular calibration of the variometer by comparison against the results of the Kew pattern absolute magnetometer was a task undertaken roughly each fortnight. On the first term day for synchronous observations with the *Gauss* and other observatories (1 March 1901), Skelton had predicted that their observatory would be a site of numerous magnetic storms. “The records, which will be continuous, show most remarkable magnetic storms to be the normal state down here" (Skelton, 2004, p. 59). This proved correct as Bernacchi often records the trace going off the scale.

Getting from the *Discovery* to the magnetic huts was not always easy. Before the sound froze it required a boat trip across to shore, then, once the sea froze and the Antarctic night enveloped the expedition a ropeway to the shore was established when it became clear how easily men could become disoriented and lose their way in a blizzard. Bernacchi's diary demonstrates this on 12 August: "Blowing a blizzard so furiously that it's impossible to get to magnetic observatory" (Bernacchi, 1902a). On one occasion Bernacchi and Skelton were lost for nearly two hours within a short distance of the ship when, as Skelton recorded, a section of the safety rope was missing (Skelton, 2004, P. 101). They wandered around and were only saved by chance when men returning to the ship from practice for theatricals in the main hut heard them calling (Royds, 2001, p. 154).

Meanwhile the meteorological observation program proceeded with records taken every two hours. This onerous procedure involved an excursion to the weather screens aft of the ship on the sea ice. Michael Barne, under the *nom-de plume* of "Fitz-Clarence", was prompted by the "eternal round of magnetic and meteorological observations" to contribute to the mid-winter edition of the in-house journal, *The South Polar Times*:

> An observation! What is that?" I think I hear you say.
> 'A scientific function that is practiced every day?'
> Not only every day, I fear, far oftener than that,
> A useless entertainment, and it fairly knocks me flat.
> To ascertain the object of this idiotic game
> Of taking measurements, is my everlasting aim.
>
> To be aroused from slumber at the deadest of the night,
> To take an observation, gives us all a morbid blight:
> How in the name of all that's blank, can temperatures down here
> Concern those scientific men at home, from year to year?

To us alone they matter, for it's cold enough alas!
To freeze the tail and fingers off a monkey made of brass

(Bernacchi, 1938, p. 50)

The Eschenhagen magnetograph ran reliably, except in the most extreme cold weather, when the rotating drum stopped. This only occurred on a handful of occasions such as midwinter 1903 when Bernacchi recorded: "Clockwork of magnetograph stopped through cold & I could not coax it to go again until today" (Bernacchi, 1902c). The instrument provided a continuous record of changes in the magnetic field for nearly two years. Bernacchi tapered back the frequency of observations around September of 1903 when his supply of photosensitive paper was getting low. On 11 September 1903 Bernacchi wrote: "Found yesterday that there are only 50 magnetograms remaining so have not worked instrument yesterday or today, & must miss days so as to make the paper cover as long a period as possible" (Bernacchi, 1902c).

Other problems encountered by the physicist were ingress of drift snow into the magnetic huts requiring hours of removal and clean up. On 16 and 17 July 1902 Bernacchi described having to clear out the variation house after the hut including the instrument bench became drifted up with powder snow. He stressed the importance of cleaning all drift snow out of the instruments so as not to throw them out of adjustment (Bernacchi, 1902a). From time to time the lamp burned incorrectly, creating smuts that soiled the apparatus. On 22 May 1902 he spent the day cleaning out the hut after a "Difficulty with hut smoking badly" (Bernacchi, 1902a). Blizzards often created additional tasks of digging away snow to access the hut doors. The physicist records that after an overnight blizzard on 13 August 1903, it took him all morning to dig out snow to gain access to the observatories.

Bernacchi's diary provides evidence that he put considerable effort into preparing for the forthcoming solar eclipse, on top of his normal range of activities.

> Have just finished computing the times etc for Solar Eclipse on Sept. 21st. It is rather a long & cumbersome computation but very interesting.
> Find the first contact will occur at 3h. 39m.54 s PM M.T. & the last at 5.37.8 PM So the duration of the eclipse is 1h.57m.14s. + magnitude of maximum phase = .94 total being = 1. So it will not be far from total. Magnetic curves for last week are very highly disturbed, especially that for 26th when bright aurora was witnessed. Also curves for 22 day the sun returned are very highly disturbed. Endeavoured to take absolute observation on several occasions during last 8 days but had to abandon attempt on account of disturbance. Observed two occultations of stars successfully this evening & took time observation with Mulock.
>
> (Bernacchi, 1902c)

He recorded that unfortunately things did not go perfectly on the day of the eclipse:

> We got everything ready for [measuring] eclipse in one of Hodgson's biological shelters viz. Prismatic camera, telescopes, Spectrometer, half plate camera etc. but towards noon cloud came up from the NE & by 1PM the sky was completely overcast & remained so all afternoon & did not allow us to catch even a glimpse of the sun. It was a bitter disappointment, after all the preparations we had made. A perceptible darkness was observed during the eclipse but not very marked-the only observations we were able to take were magnetic and meteorological.
>
> (Bernacchi, 1902c)

The experience on Drygalski's *Gauss* could not have been further from that on *Discovery* as the *Gauss* never landed a shore party. The ship became ice bound at a high latitude at sea (66° 02' S, 89° 38' E) and physicist, Bidlingmaier had to accommodate his magnetometer on the sea ice. For the first term day observation he set up his equipment on a floe, in the open air, as shelter had not yet been built. An icehouse was constructed later on the floe, but due to snowfalls it began sinking, the water level rose and Bidlingmaier worked standing in a pool of saline slush at -5° C. A second icehouse observatory was built later but movement of the floes caused it to continuously move further away from the ship. Bidlingmaier made a sledge journey from the ship in the interests of science. He travelled to the coast to take observations on solid land that allowed him to calibrate the instruments, enhancing the value of results (Drygaski, 1989, p. 233; Vanhöffen, 1915).

## 6.3 Sledging journeys and scientific operations

There were four sledging journeys undertaken during the *Discovery's* period in the ice that are of particular significance to the magnetic research. These were:

- Scott, Wilson and Shackleton's southern journey between November 1902 and February 1903
- Armitage, Skelton and Ferrar's western (polar plateau) journey between November 1902 and January 1903
- Scott's western summit party between October 1903 and December 1903
- Bernacchi and Royds' southeast barrier party between November 1903 and December 1903

(Yelverton, 2000, pp. 381-383)

These journeys provided data on declination that became data points used in Chart 1, plate 17 of the *Physical Observations* report that located the magnetic pole and that displays lines of variation in the Ross Sea vicinity (Figure 9). The western journey of Armitage, then the Barrier journey of Bernacchi and Royds provided complete sets of magnetic observations for declination, dip and total force.

*National Antarctic Expedition*, 1901–1904. *Plate* 17 (*Magnetic Observations*).

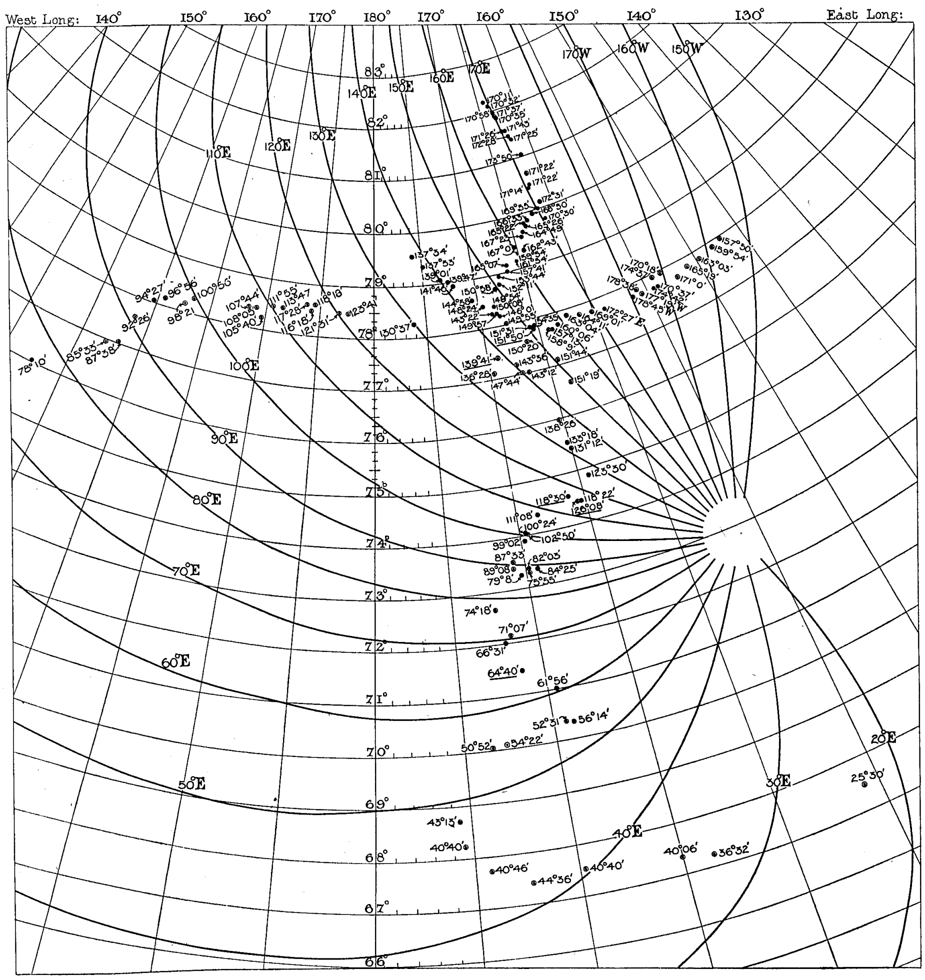


Chart I. Lines of equal magnetic declination. (See p. 155.)
From observations made by the Officers of the National Antarctic Expedition, 1902–1904.
By Commander L. W. P. Chetwynd, Royal Navy.

Figure 9: Chart showing magnetic data collect points at sea, at Winter Quarters and on significant sledging journeys 1901-1904, south geographic pole near top (Royal Society, 1908, Chart 1, following page 156).

The terminology used in the diaries and narratives hints that the sledging journeys were an extension of maritime exploration in practice, except that instead of liquid water the substrate was a frozen sea, river (i.e., a glacier) or ice cap. Armitage mentions that they "unshipped the wood" from the sledge runners early in his western mountain journey in spring 1902. In his sledging diary during the "Barrier" trip, Bernacchi stated on 14 November

1903: “Mt. Erebus and Terror now well astern” and on 2 December 1903: “One is entirely dependant upon astronomical sights and compass for position. In this respect similar to a ship on the open sea” (Bernacchi, 1903c). Scott himself alludes to maritime practice when describing the use of a tent floorcloth as an aid to sledging: “This floorcloth spread on bamboos likewise made an excellent sail, but could be used in this capacity only when the wind was abaft the beam” (Scott, 1905b, Volume 1, p. 429). These allusions, along with the use of sledging pennants to identify the commander of each of the sledges, follow historic maritime practice rooted in antiquated RN Arctic traditions from the previous century. Scott did not know at the time, but the whole of his southern journey on this expedition was across floating barrier ice. Royds found evidence that it was afloat when he determined higher temperatures deep in crevasses on the Barrier, indicating proximity to seawater during the south-eastern barrier journey.

In accord with normal maritime practice, spot checks of position were made at least daily, especially solar zenith observations for latitude at local noon. Sextant observations rely on a clearly defined sight of the horizon or the use of an artificial horizon as, in polar environments it’s often impossible to discriminate the horizon from sky. The artificial horizon consisted of a small mercury bath offering a horizontal surface that reflects an image of the sun. The theodolite would have been the more accurate instrument but sextants were more portable. Correct technique for use of the artificial horizon is shown at Image 9. The low sun and atmospheric effects further complicate observations and reduce accuracy (Littlehales, 1904). The compass was of little practical use in navigation due to proximity of the magnetic pole where the weak horizontal force meant that the needle was sluggish and the declination was great.

Image 9: *At 65 miles, Southern journey. Bage instructing Hunter in the use of the artificial horizon* (McLean, 1912). Reproduced with permission of Mitchell Library, State Library of NSW.

Scott's southern journey was purely for exploration. Armitage's spring 1902, western mountain journey turned out to be a pathfinding journey in support of Scott's 1903 longer summer journey that penetrated the Royal Society range and made considerable mileage across the polar plateau towards the west. Armitage's journey was minor by comparison to those of Scott in total distance but significant in geographic achievement as he discovered the Polar Plateau and found the way through the range. His last outward camp, on the polar plateau, was 101 miles (160 km) from the coastline and 134 miles (216 km) from the ship (Armitage 1905, p. 182). Armitage stated his intention to make numerous, full sets of magnetic observations en route. On the sea ice on the western side of McMurdo Bay, and before commencing the ascent of the Ferrar glacier, Armitage and Skelton detached from the main party to make the first set of magnetic observations (dip, total force and declination). The full instrument kit and tripods together made a significant addition to the weight of the sledges of 47 lbs., or about 21.5 kg (Armitage, 1905, pp. 158-162). The value in respect of magnetic science was that "we had, by fortunate coincidence, travelled on a circle of equal 'dips,' thus greatly aiding Commander Chetwynd, R.N., who undertook the 'working up' of the observations on our arrival in England, in fixing the present locality of the Magnetic Pole" (Armitage, 1905, p. 187).

Scott's western journey was also exploratory, not scientific. It's a mystery that the declination chart published in the *Physical Observations* volume of scientific results shows observation points with longitude and latitude on that track, yet Scott acknowledges that his means of accurately calculating his position from sextant or theodolite observations, the *Hints for Travellers* booklet, "containing essential data and tables for finding latitudes and longitudes" was lost from the supply depot at the top of the climb onto the polar plateau. Armitage quotes a letter from Scott that explains he extrapolated the curve of magnetic declination then navigated by compass, working out "how far we got, and, roughly, what the variation was at different points" later after returning to the ship (Armitage, 1905, pp. 278-280). Bernacchi, in contradiction, states that he applied his "fine knowledge of Nautical Astronomy" to compile from his existing observations a workable version of the necessary data (Bernacchi, 1938, p. 94). These were probably the least reliable data points for location from time on ice.

Beyond the ramparts of the mountain range Scott's outward and return tracks lie on much the same latitude. He appears to have used the ancient sailor's method of using the height of the sun at its zenith to determine the latitude and his data points for longitude must have been determined by dead reckoning using sledgemeter records. This data is summarised in Table XVII of the *Physical Observations* and is expressed in degrees, minutes and seconds of longitude and latitude, or an accuracy of better than 10 metres, but there is no commentary regarding the true limitations to the accuracy of the positions (Royal Society, 1908, p. 154). The data from Armitage's western mountain journey appears in Tables X and XI of the *Physical Observations* volume and is expressed in degrees and minutes only, meaning accuracy to within about 500 metres (Royal Society, 1908, p. 143). One would have expected the accuracy of these positions to be reversed in the light of Armitage being equipped with navigation instruments and tables, while Scott was estimating longitude by dead reckoning and determining latitude by zenith observations. On 22 November 1903, on the outbound journey, Scott's party crossed a point exactly between the geographic and magnetic poles, so the magnetic declination was 180° and the south geographic pole appeared to be due north by the compass (Scott, 1905b, Volume 2, p. 257).

The final and most significant of the sledging journeys was that undertaken by Bernacchi and Royds in late spring of 1903, referred to as the "Barrier" journey. This journey was towards the south-east, across the ice barrier from Hut Point. Bernacchi had lobbied Scott for this journey during July of 1903:

> Had an interview with the Captain yesterday & requested him to allow me to undertake a sledge journey out on the barrier in a SE direction. The journey to last 30 days & party to consist of 6 in all.
> As I had not got away on sledge journeys last year on account of the physical work to be done, would like to get an opportunity this year. The sensitive paper for the magnetograph will not last the whole year. There will be a break of at least 2 months so might as well employ that time in sledging. Captain seemed much [unintelligible] with the scheme, but there is some difficulty in getting men + equipment. However he is going to think it over + let me know in a few days.
>
> (Bernacchi, 1902c)

Bernacchi does not mention whether he used the scientific utility of the journey as an argument to gain Scott's agreement, but *his* prime purpose was to make magnetic observations away from the influence of the rocks on Ross Island that he knew were affecting the results. He had previously established a tent observatory out on the sea ice, to the west of Hut Point, to escape the magnetic influence of the substrate. His 5 October 1903 diary entry records: "Large tent erected 1 ½ Geo miles in a W direction for magnetic work in November" (Bernacchi, 1902 c). In the introductory note to the *Physical Observations* report, Bernacchi noted:

> The results differ considerably from those taken on shore, and indicate a larger dip and a smaller value for the Horizontal Force, whilst the Declination seems less easterly. These observations were the standard sets taken as being most undisturbed, and used as the base to which all the observations on board the 'Discovery' were reduced.
>
> (Bernacchi, 1908, p. 131)

The Barrier journey was also exploratory in nature and to investigate the form of the ice barrier in that direction. Royds also wished to supplement his Hut Point meteorological data as it was known that there was a distinct microclimate operating in the vicinity of Winter Quarters. Scott recorded the objectives of this sledging party and there is no mention of magnetic studies.

<u>Objectives for Sledge Parties 1903</u>

Royds & Bernacchi

Careful examination of Barrier surface, examination of crests, temperature in holes, spaces between crests, nature of crystalline structure especially under crests, dig holes, take cooker water from various depths & examine snow by measuring resultant water.

<u>The main problems</u>

1) To obtain evidence as to the packing due to supercumbent snow, a problem mostly connected with the thickness of barrier & bergs.
2) To ascertain if the crusts and stratification in general can be considered seasonal
3) To determine the depths to which the surface temperatures penetrate below the surface.
4) To discover any inequality of level

(Scott, n.d.c)

Bernacchi's objectives for the journey were recorded quite differently before departure and stress scientific, not geographical objectives. This is evidence that Scott may not have been completely in touch with the work of the scientific programs.

Scientific Programme Barrier Sledge Journey 1903

1. Magnetic observations! Inclination & total force with Barrow Circle declination with prismatic compass.

2. Specimens of air for dust & chemical analysis

Specimens of snow from various depths in [illegible]

Specimens of solid ice (if found) from the furthest point for Ferrar

3. 2 holes that are dug measure with tape width of respective bands, icy layers … of any kind such as 'blue veins' 'white veins', 'dust bands' etc.

4. Observe any effects of thaw on surface + below temperature in holes

5. If possible observe structure of ice grains below surface /size, form, arrangement + time to separation when exposed

6. Observe direction of crevasses & sastrugi + depth & height respectively

7. Observe crusts; hollows; & uplifts

8. Rock, moraines etc

9. Careful observations at lowest point of barrier (if reached)

(Bernacchi, 1903a)

This note confirms that Bernacchi used the Barrow dip circle in preference to the Lloyd-Creak dip circle that had given Armitage trouble on the outbound voyage. The eyepieces and adjusting controls would have been fitted with leather covers to protect the skin of the observer. Once past Cape Armitage the track extended away from the magnetic pole in a south-easterly direction. A complete record of the journey and the magnetic science undertaken is accessible in the form of Bernacchi's sledging diary, the original notebook being held at the Thomas Manning archive of the SPRI, Cambridge (Bernacchi, 1903a) and an expanded, typed version in a private collection of a descendant (Bernacchi, 1903c). Although he provides little description of the social landscape and only nominal detail of the geographical landscape, the diary offers a great deal of information about the navigational and scientific work.

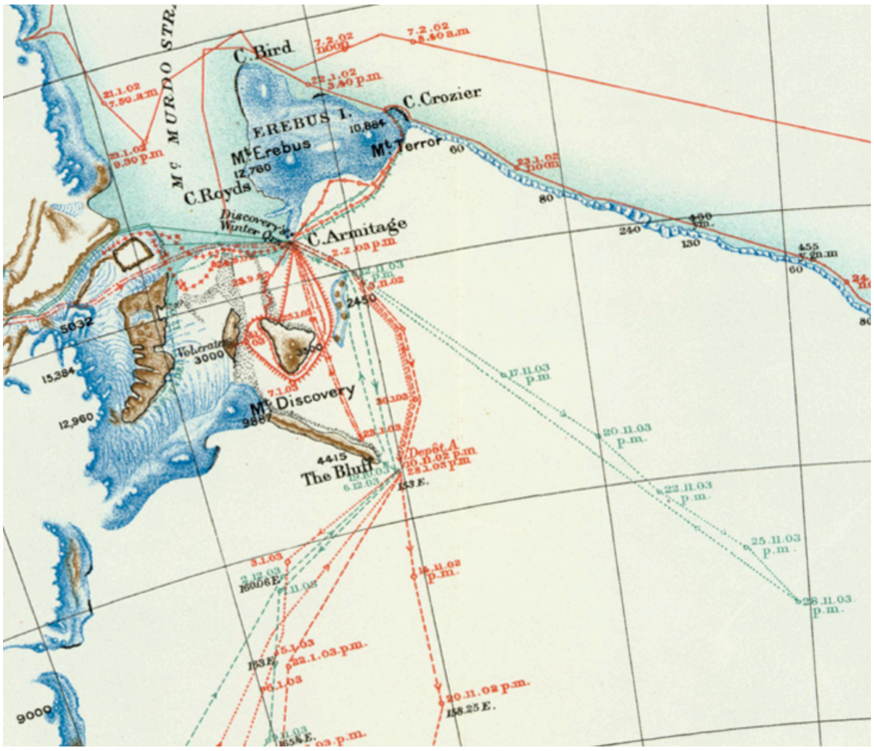


Figure 10: Detail from Mulock (1904) showing path of Bernacchi & Royds south-eastern Barrier Journey.

The following segments from one day's entry (17 November 1903) are typical:

> Tried to get sun sight at noon for latitude but failed through cloud obscuring sun… Took sight for longitude about 5.30 PM but not the best through sky being partly cloudy…After supper took set of magnetic observations in tent. Both dipping needles and total force. Dip has increased (sic) to about 85° 46' & total force appears to have considerably decreased indicating increase in horizontal force. Lat approx. 78° 33' South by 170° 22' 15"
>
> (Bernacchi, 1903a)

His comment that the dip has "increased" is in error as the previous dip measurement on 14 November stated: "Magnetic dip about 85° 58' ", so the dip, as expected (moving away from the magnetic pole) has decreased.

The expeditions had a variety of "portable" observing instruments for use on sledge journeys. The instruments were a significant part of the weight to be shifted, and man hauling was the only transport option as all the adult sledge dogs had perished on Scott's southern journey in the previous season. Royds stated that the Barrow dip weighed 18 lbs. (~8 kg.) and its tripod added 10 lbs. (4.5 kg.) to the sledge weight (Royds, 1903). This is a lower estimate than the kit used on Armitage's western trek. Bernacchi was using a sextant and an artificial horizon to determine position, as way finding on the Ice Barrier was no different to navigation at sea, there being no landmarks for reference or any visible horizon. He noted that, at the end of each third day's sledging he took his full round of magnetic observations in the tent, usually before cooking and camp preparations commenced. In addition, Bernacchi was making the time to perform all the necessary calculations related to position finding and the magnetic observation results. Webb provides the most succinct description of conditions and operations during field magnetic observing activities in his memoirs of the journey performed with Bob Bage (1888-1915) and Frank Hurley (1885-1962) during Mawson's AAE. The men sledged from the Commonwealth Bay base station to the region of the South Magnetic pole, but this was not reproducing Mawson, Mackay and David's earlier trek (reached initially on 16 January 1909 at 72° 25' S, 155° 16' E). Bage, Webb and Hurley approached from the north, on this occasion crossing completely new territory. Mawson had the advantage of an advance copy of the *Discovery* magnetic report as a source during his earlier journey (Shackleton, 1932, p. 307).

> Each full set of observations entailed a minimum of 2½ hours actual observing, when 250-300 instrument readings would be made: at the extreme south station, where dip in planes at right angles had to be followed, the readings were nearly doubled. When allowance is made for unpacking, setting up, organising windbreaks and waiting for workable conditions of visibility or wind, each station absorbed at least 4 hours-rather a back-breaking feat of endurance for the observer and perishing cold for the recorder who always had my profound sympathy.
>
> (Webb, 1965, p. 5)

Bernacchi mentions that, as the party progressed away from Hut Point the dip and total magnetic force decreased, and the horizontal force and declination increased. The navigation calculations alone required sextant observations in the morning and afternoon for longitude, and midday, solar zenith measurements for latitude. Bernacchi was troubled by snow blindness from time to time and comments on his state of exhaustion and constant hunger. Gregory had written that man hauling sleds and performing scientific surveys were incompatible. Man hauling exhausted the participants, dulling their senses and reducing their capacity for inquisitive observation or scientific activity: "Secondly, one cannot expect men who are harnessed to heavy sledges to keep sufficiently alert mentally to observe accurately and solve the new problems that will be presented to them. Travellers have often been blamed for errors due to their having seen things with perceptions blunted by continued manual labour." Gregory also comments on the need for shelter and rejected Peary's ideas that tents are unnecessary. The scientists needed the capacity to write up daily results and observations in an environment that was conducive to intellectual activity (Gregory, 1900a).

Webb's memoir of the sledge journey to the region of the magnetic pole in 1912 further describes care required by the operator of a dip circle in the field and some challenges faced in the interests of quality results.

> The dip-circle is a delicate mechanical instrument, depending for precision on the skill, care and experience of the manipulator, even in a favourable environment. When competing with low temperatures and high winds involving dust, snow and ice, these attributes are at a premium. Because of its design (for use on ship-board), the Lloyd-Creak type is the more difficult to handle and is less dependable for accurate results than the Kew.
>
> (Webb, 1965, pp. 2-3)

Murray Levick, of Scott's *Terra Nova* expedition (under the pseudonym of "Bluebell") wrote a humorous but instructive poem that well describes the process of taking dip readings in the field with the Barrow dip circle.

**The Barrow Dip**

The day being calm we take occasion
To make magnetic observation
With Poles direct and B end dipping,
We don’t care how the frost is nipping.
With instruments first facing east,
Who minds such hardships in the least?
So merrily we crack our quip,
The while we work the barrow Dip.
And, stamping on the creaking snow,
Shout, “Right away, boys! Let her go!

With face of instruments now west
The little needle seems possessed.
Ye gods! The fun is waxing warm:
This must be a magnetic storm.
We stop to find the reason and
Find some one’s been and kicked the stand.
For though a tripod was at school
Declared to be a three-legged stool,
This toy would seem to have indeed
Enough legs for a centipede.

The instruments being once again
Adjusted on a level plane,
And the offender roundly cursed,
We start again with poles reversed,
And watch the swinging needle bend
Its upper then its lower end,
And noting twice which way it lean,
First take the sum and then the mean.

The worker’s hands are numb with cold,
His nose a wonder to behold,

All this we've done, but don't forget
The fun's not nearly over yet,
Because there still remains of course,
The three times cursed magnetic force,
The jest this time is much increased
(With both the needles facing east).
We fix (as we are told to do)
The north end near the tangent screw,
Nor do we heed the chilly air,
But note each reading down with care,
Then on our frozen limbs we rise,
And fill the air with joyous cries.
We'll go and make a huge repast-
The beastly thing is done at last!

(Priestley, 1915, pp. 189-190)

On 28 November, after eighteen days travelling, the party under Royds' command turned for home at 79° 35' 2" S, 175° 55' 30" E, after making a complete set of magnetic observations and various meteorological and glaciological activities, including air sampling and taking ice crystal samples from a deep snow pit. They had travelled a "distance of exactly 155 miles = 178 statute miles" (286 kilometres). Bernacchi describes the landscape thus: "At the present we see nothing, on our horizon the barrier is one uniform dead level, no inclines nor declines & scarcely an irregularity" and "One huge white waste all around with less diversity than the Great Sahara desert" (Bernacchi, 1903c). The return journey was a bolt for home and is barely recorded by Bernacchi. The return was characterised by following winds that allowed use of the tent floorsheet as a sail on the sledge. The party had averaged 10.2 miles per day (13.2 Km) for the journey (Skelton, 2004, p. 191) and achieved a significant amount of scientific work in spite of the nine hours daily sledging and the usual time spent making and breaking camp.

## 6.4 Organisation and leadership on the ice

### 6.4.1 Hierarchy

Once south of New Zealand Scott had the weight of responsibility for the whole expedition firmly on his shoulders. He was then operating according to the Joint Committee's official instructions, any unofficial instructions that Markham may have given him, and his own wits. He was truly at the periphery and enacting the first stage of the model of colonial science recognised by Basalla (1967) and Macleod (1982). Scott maintained the RN hierarchy throughout the period when the ship was south of New Zealand, even though there was no RN authority. As mentioned previously at section 4.1.4 (p. 92) the ship was privately owned by the societies and registered as a private yacht to Markham, to avoid the Board of Trade regulations about loading (Bryan, 2011, p. 151). The RN fiction was especially tenuous when the expedition became essentially a land party. The scientific party was not part of the chain of command although the participants were treated as if they were officers. Bernacchi believed that the officer/crew divide was conducive to social harmony and reflected later that this system worked: "The traditions of the naval service, which in some things might have proved a disadvantage, in the trivialities of day to day living, were of infinite benefit" (Bernacchi, 1938, p. 44).

Once at Winter Quarters the ship became the lodging. Scott maintained routines that were familiar to the officers and crew including deck scrubbing, Saturday afternoon "make and mend" sessions for the lower deck, Sunday morning ship inspections and divine service. For the officers and scientists there was the maintenance of formal wardroom evening dining routines, including appointment of a president to oversee mealtime behaviour (Bernacchi, 1938, p. 44). Skelton blanched when Scott acted outside the normal chain of command protocol and publicly reprimanded a member of his engineering section. The windmill constructed for power generation when the ship was in Antarctica broke up in a gale on 13

April 1902. This device was a pet project of Scott's so it's demise upset him greatly. Scott blamed Dellbridge, Skelton's second engineer, publicly and unreasonably, prompting Skelton to record "Most unfair, I call it, as I am responsible for it & if he wants to find fault he can go for me about it, not for men under me" (Skelton, 2004, p. 76). The scientific staff had considerable freedom to go about their business, which they did with the invaluable support and assistance of seamen.

### 6.4.2 Scientific leadership on the ice

Scott's effectiveness as a scientific leader on this expedition remains an open question. His scientific leadership at this time could not be described as energetic or instructive, nor could it be considered obstructive. His scientific leadership on the ice was benign, only requiring the scientifics to note their weekly activities in a written record kept available for access by the other scientists who might be interested. He was ill prepared for the role as a consequence of his career as a naval officer in the period prior to the Admiral Jacky Fisher regime, when drill and presentation were the focus. The curriculum for trainee officers was focused on engineering and navigation, not science, and its status was equivalent to a "senior technical school" (Dickinson, 2007, p. 5). Even by 1914 the science component had not advanced further than "easy mensuration, hydrostatics, mechanics, heat, and the most elementary outlines of magnetism and current electricity" (Director of Naval Education, 1914). There was no natural science in the curriculum aside from the meteorology element of the geography classes. Any relevant scientific knowledge would have been acquired at torpedo school and during the brief spell of magnetic training prior to departure. Reading during the outbound voyage might have enhanced his depth of knowledge. He would have observed the methods of Mill and Murray in the Atlantic but his personal diaries rarely mention scientific operations (Larry Conrad, personal communication, September 2011; Ursula Rack, personal communication November 2012). The notable polar scientific leaders of the era (Mawson, Bruce and Charcot) had personal scientific aspirations that fostered the intellectual climate amongst their experienced, well trained and well equipped scientists. Those leaders were highly motivated to get the best performance from their scientific teams, whereas Scott's prime motivation (on the *Discovery* expedition) was geographic exploration. His later, *Terra Nova* expedition had a stronger focus on scientific outcomes and was staffed by scientists of a higher calibre than the *Discovery*. Bernacchi reflected:

> But Scott had a deep and reverent attitude towards nature and a most genuine love of science. He was interested in every branch of research carried on in *Discovery*, and frequently made original suggestions to the workers. He could have been a scientist or…
>
> (Bernacchi, 1938, p. 212)

Bernacchi's work was nearly all regulated by the strict observing routines of term day cycles and the requirement to keep the Eschenhagen magnetometer running continuously. He seems to have performed his non-magnetic physics work at his convenience and in a completely self-directed manner. Scott did design and execute one experiment of his own on the microclimate of the locality around Winter Quarters during the *Discovery* expedition. Bernacchi's diary for 26 April, 1903 records Scott's effort:

> … to find exactly where between thermometer in strait between C. Ar. [Cape Armitage] & ship the temp commenced to differ appreciably for there is generally a difference of something like 10° or 12° & found that as soon as he left the shore of Cape A. it commenced to drop … in proportion to the distance from it.
>
> (Bernacchi, 1902c)

Scott also developed the idea for a current indicating device similar to a wind vane, but embedded into the sea ice (Skelton, 2004, p. 87).

Although Scott is widely credited as being interested and engaged with the scientific program and capable of posing big picture questions, it's unclear whether he really assisted and promoted the scientific program on the *Discovery* as much as a leader who was a scientific scholar, like Gregory, Mawson or Bruce might have done. Praise of Scott as a scientist is a phenomenon that commenced after the *Terra Nova* expedition had concluded in 1912, and the evidence suggests that although he was naïve as a scientist at the commencement of his *Discovery* experience, he developed rapidly. Priestley, the respected polar scientist and member of both Shackleton's *Nimrod* and Scott's *Terra Nova* expeditions, praised Scott's scientific acumen (Priestley, 1915, p, 25).

One area of speculation is the consequences if Gregory had still been the scientific director when Scott decided to keep the ship in the ice over winter. It is probable that there would have been a clash of wills regarding the missed opportunities for coastal dredging, trawling and netting. In reference to US activities during the International Geophysical year (around 1957), Belanger states: "A dual command system, a reluctant compromise both civilian and military leaders deplored, proved generally workable and effective in the reality of polar camp life" (Belanger, 2006, p. 5). But there were some famously difficult relationships between scientific expedition leaders and ship commanders during the early part of the twentieth century, for example Filchner on *Deutschland* (Turney, 2012, p. 195) and Mawson on the BANZARE *Discovery* expedition (Rice, 2005). The scientific leadership vacuum evident on the outward passage of the *Discovery* continued to be evident on the ice.

### 6.4.3 Logistics and transport on the ice

Scott's choice to keep the ship in Antarctica over winter of 1902, and thus unintentionally also 1903, was a logistical decision that had knock-on effects to the scientific achievements. The ship and adjacent huts became the home base for all exploration and scientific activity. The ship-based oceanography and zoological collecting ceased for the duration of the entrapment, and the sciences that were favoured by collection of continuous data sets at one site (meteorology and terrestrial magnetic studies) benefited from the enforced stay. The balance between exploration and scientific inquiry was regulated by the overwintering decision. Scott had absolute control of scientific fieldwork through his allocation of the resources of equipment and men to the various sledge journeys. Scientific inquiry was a secondary consideration with only a handful of sledging trips being made specifically in the interests of science.

If a shore party had been dropped in accordance with Professor Gregory's plan it would most likely have consisted of about twenty men including Scott, Wilson, Skelton, Koettlitz, Bernacchi, Royds, Shackleton, Barne, Ferrar, some seamen and a cook. This would have left a skeleton crew commanded by Armitage to continue coastal exploration and scientific work at sea and to possibly undertake some opportunistic, short overland sledge journeys. In that case only a handful of expeditioners would have been available to travel off base. Of the total party of twenty overwintering, there would probably have been sufficient manpower available for three sledging outfits, assuming an emergency reserve at base and at least three persons remaining to tend to the magnetic and meteorological observations. The exploration and field science would have been nominal compared to the numerous sledging journeys actually achieved. Yelverton summarises the actual journeys in his appendix where he shows that during November 1902 up to six parties comprised of a total of twenty-four men were able to go off-base simultaneously and still have a reserve emergency team (Yelverton, 2000, pp. 381-383). Equipment such as sledges, tents, sleeping bags and cooking apparatus rarely seemed to have been limiting factors on the logistics of sledging operations, although Bernacchi notes on 3 July 1903 that this was the case for the Barrier journey of November 1903 (Bernacchi, 1902c).

Ferrar turned to spending a great deal of time at meteorology and ice studies since he quickly collected all the samples and performed the analysis required on the geology of the Hut Point locality (Ursula Rack, personal communication, November, 2012). He also expanded his scope of geological work by taking part in nine sledge journeys during the stay in Antarctica. Wilson lamented that he was taken away from the coast, the scene of biological activity in spring and summer, on the southern journey with Scott and Shackleton:

> I am afraid this long southern journey is taking me right away from my proper sphere of work to monotonous hard work on an icy desert for three months, where we shall see neither beast nor bird nor life of any sort nor land and nothing whatever to sketch. (Savours, 1966, p. 207)

Hodgson might have been able to dredge and trawl on McMurdo Sound and expand the diversity of benthic organisms secured as specimens if a boat had been available and there was sufficient manpower to shift it to the ice edge. The ship's boats were buried in the floe, open water was kilometres from Winter Quarters and the men were fully occupied with support to sledging parties.

## 6.5 Ice-craft

Survival and travel skills in polar conditions were not strictly operational elements of the scientific program, but they were factors contributing directly to the productivity of the scientists. Scott and his team were generally deficient in experience or acquired knowledge in most matters germane to life and work in the polar environment. At the end of the March 1902 "Sledging had been a failure. Food, clothing-everything was wrong. There would be much to think about, and much to rearrange during the long winter night" (Bernacchi, 1938, p. 40). The death of seaman Vince, whose demise resulted from a combination of factors, was a signal to the expedition leadership. He had incorrect footwear on an ice slope and there was a poor management decision (by Royds) to break a field party into two groups whose members were all novices and who were unfamiliar with the terrain across which they were instructed to make their own way home. Vince's party had inexperienced and less senior leadership (Barne) and the decision to cache survival equipment and push on towards the ship in deteriorating weather was unwise. This preventable loss of life so early in the stay at Winter Quarters must have alerted Scott to the need for more caution and deeper consideration of the challenges of day-to-day work in the harsh environment. Scott does not accurately record the extent of Barne's own injuries but he was so frostbitten that his "hands were in slings for over two months during which time he had to be fed by others" (Bernacchi, 1903b). It may have also alerted Scott to the fact that productive scientific work could not succeed unless the other support systems were securely in place to facilitate field operations.

The management of the dogs on the expedition is an example that demonstrates inexperience and a failure to take advantage of readily accessible knowledge or learning opportunities. The use of dogs was a footnote in the *Discovery's* transport and logistics strategy as nearly all of the work was traditional manhauling following the nineteenth century Arctic RN tradition. Bernacchi noted in his narrative *Saga of the Discovery,* that even in 1902, manhauling was an outmoded form of polar transport and that Scott saw nothing incongruous in making men do the work of draught animals. Dogs were regarded more as pets and companions, not working animals (Bernacchi, 1938, p. 64). Although dog teams were in everyday use in Siberia, Canada and Alaska, dog management and handling remained a mystery to members of the *Discovery* and no specialist dog handlers were included in the expedition membership. The dogs suffered through the cold of the first winter (in spite of the wasted effort on construction of dog kennels) as their body rhythms were still running according to northern hemisphere moult cycles. A great deal of effort was wasted when a decision was made that the Siberian harnesses were deficient in some way. New harnesses were developed and fabricated during the first Antarctic winter at great expense of time and effort. They were a dismal failure as they were "guaranteed to twist the dogs & chaff the hair off in a surprisingly short space of time" (Bernacchi, 1902a) and were abandoned after the trials (Bernacchi 1902d). Describing the departure of the Southern Party on 30 October 1902, he recorded that the new "patent dog traces carried away" so the "good old antiquated" traces were substituted (Bernacchi, 1902b). Ignorance was further demonstrated by having three breeds of dog mixed together, leading to fatal fights. In mid February 1902, soon after getting snug at Winter Quarters, conflicting opinions about how to conduct dog-sledging operations resulted in a "competition" (no doubt attended by betting) between Bernacchi and Armitage. There are different versions of how the event transpired. Each trained up dog teams using different methods and different technologies for the equipment. Bernacchi won the race, but without any control of the team. He claimed complete victory. Bernacchi's own journal account related the rules for the event:

> A discussion arose at dinnertime upon dog training & driving which resulted in my entering into a competition with Armitage to each break in a team of dogs after his own fashion. The later contended he would have his team in hand before I would mine. He was to use expedition harness, muzzles and whips. Whilst I was to make my own harness & use neither whips nor muzzle.
>
> (Bernacchi, 1902d)

Armitage potentially had the upper hand, having taken part in all the major sledging journeys of the Jackson-Harmsworth Arctic expedition where dogs and ponies were used. Although Bernacchi had overwintered with the *Southern Cross* expedition at Cape Adare, that camp was unfortunately sited adjacent to an insurmountable grade up to the Admiralty Mountains. Intended sledge journeys to the interior were not possible and journeys across the sea ice were not of great significance (and not science related) in spite of the ninety Greenland and Siberian dogs which were attended by two Lapp grooms who "were skilled in the management of dogs, and could work for hours beside the sledges without showing any sign of fatigue" (Bernacchi, 1901a, p. 89). Bernacchi describes the race in a sanguine tone although the diaries of Royds and Skelton show he had no real control of the dogs that had bolted without their driver. The description indicates a knowledge vacuum regarding arrangement of the dogs in the traces, construction of the harness, control of the dogs and a lack of foresight to break the dogs into harness during the winter:

> The sledge competition came off today & my team of 12 dogs were victorious. The harness employed appeared to have some advantages over that used by Armitage. Had my dogs harnessed as follows two abreast to the long rope attached to the front of the sledge. A broad canvas collar fitting well down on to the breast at the bottom of the collar a trace made fast & running in between the legs: A belly band to keep the trace in position & a short line with a swivel at one end attached to leading rope & hooking into the collar to keep pairs of dogs abreast.
>
> The harness of the other team was more complicated. Was made in one piece but kept continually fouling the dog's legs so frequently that they had to run along on three legs only. They were not fastened abreast but one in front of the other on alternate sides of the rope. Many of the dogs are young & not broken in to harness.
>
> (Bernacchi, 1902d)

Savitt thoroughly reviews the evolution of knowledge of sledging practice by polar expeditions. He concluded: "Robert Falcon Scott, in great part as a result of his naval heritage, did not fully understand the need for and the methods required to gain the operational knowledge required for sledging in Antarctica" (Savitt, 2004). This is surprising since Nansen had counselled Scott on the matter and there had been a very long history of RN Arctic expeditions where contact with Inuit and Canadian voyageurs (fur traders) could have informed expeditioners. Scott's narrative (Scott, 1905b) does not indicate any acquisition of indigenous knowledges about polar survival or transport, or to learn from recent polar explorers, even from his visit to Nansen.

Arctic Indigenous knowledge that would have been of great utility to the *Discovery* included the fact that great daily distances were possible using dog teams: "We made up to ninety-five kilometres a day, though our dogs were not in the best condition" (Freuchen, 1935, p. 195). One continual challenge to Scott and others of the era was the difficulty of travel across soft snow. The indigenous communities of Greenland knew the answer that was to lash hide onto the sledge runners, then pour melted water over them (or urinate on them) allowing it to freeze into a thin layer of ice. The result is that "With such runners much greater loads can be hauled over the loose snow….It took us twenty-four hours to prepare the sledges but when we finished the sledges were almost as easy to shove as a baby carriage" (Freuchen, 1935, p. 194). With this knowledge the course of history on Scott's second expedition might have been dramatically different. Other simple techniques like leaving the dog traces short to allow faster turns and "an old trick … harnessing the bitches in heat among the forward teams; then the team of dogs where they really belonged could haul any load in order to catch up to them" (Freuchen, 1935, p. 192). As there were few dogs with the *Discovery* and they were not considered a primary transport choice, these points are of little relevance now, but opportunities were missed as a consequence of ignorance of these matters. Scott reflected after the first autumn sledge journeys "In one way or another each journey had been a failure; we had little or nothing to show for your labours. The errors were patent; food, clothing, everything was wrong, the whole system was bad" (Scott, 1905b, Volume 1, p. 273). The critical point here is that scientific field work could have been more prolific and more successfully acquitted if effective dog transport had been used to support the field parties. Scott had been in favour of dogs after discussing the matter with Nansen during their meeting in Oslo in October 1900, but Markham subsequently dissuaded him from that view (Yelverton, 2000, p. 33).

There was a failure to include certain titles that might have directly informed sledging practice and polar survival in the ship's library. George Murray's letter to Markham indicates that he and Scott assembled the library: "Scott and I start tomorrow on a raid on the publishers for general literature" (Murray, 1901e). The library catalogue was compiled onto a booklet (National Antarctic Expedition, n.d.). Bernacchi mentioned the deficiencies:

> …although *Discovery* possessed a library of several thousand books, and among them several on Arctic exploration, by some oversight those which would have been of most assistance had not been included. We could gain no advantage from the experience of the more recent explorers, Nordenskjöld, Nansen and Peary.

(Bernacchi 1938, p. 56)

Skelton must have acquired a private copy of Nansen's *First Crossing of Greenland* as he was reading it in June 1902 (Skelton, 2004, p. 97) but Nansen's *Farthest North* was not in the collection (Yelverton, 2000, p. 159).

## 6.6 The human element

The long outward voyage had allowed Scott to make judgements about the mettle and suitability for the work of crew members and eject them before turning south. At the Cape and at Christchurch crew who were incompatible were dismissed. At the Cape, the merchant seamen Mardon and Masterton were dismissed and at Christchurch the cook, Roper and the steward Dowsett were also discharged, the former listed as "objectionable" and the latter as "useless" by Markham (Markham & Holland, 1996, pp. 103-104).

Bernacchi, when he was musing about the prospect of another winter in the south, recalled the effects of polar ennui and the social climate during the first year and described the social landscape during the severe winter conditions:

> I must say I dread another of these long, dreary and bitterly cold winters. I am sure you cannot conceive how desolate and lonely it is down here. However, I dare say we shall get through it all serene while there is not the slightest discord on board. Captain Scott is held in great respect by all and we are well capable of organizing entertainments for ourselves. Scurvy is the only thing we have to fear…
> The winter on the whole was severe and very windy. There were 120 days without the sun nearly twice as long as at Cape Adare. Day after day the temperature fell below -40$^{o}$F and very frequently below -50$^{o}$. The lowest temperature was -62F or 92$^{o}$ below the freezing point. But it was a cheerful winter, all were in the best of spirits and all managed to do a good deal of work notwithstanding the cold.

(Bernacchi, 1903b)

During the polar winter various activities and entertainments and celebrations were used as a means of keeping men busy, warding off ennui and mental instability. These included games, crafts, reading for pleasure, theatricals, sports days and production and publication of the *South Polar Times*. Most officers and men also tried photography as a recreation (Judith Skelton personal communication, 30 August 2011) and there was no apparent shortage of chemicals or paper. Koettlitz and Bernacchi both attempted colour photography but the difficulties of the technology were a great challenge (Jones, 2011, p. 178). Winter routines followed old Arctic RN traditions of busy work for men during the period of darkness when sledge travelling was untenable. Most of the scientific activity slowed down and activities were required as the crew were relieved of afternoon duty during winter. Outbreaks of conflict were uncommon on this expedition but one notable event near the onset of the polar night deserves comment. Seaman Smythe became violent on the evening of 16 April 1902 and threatened to hack off the heads of his messmates before climbing up onto the awning cover. Dr Koettlitz gave him a sleeping drug when the affair was de-escalated. “It’s possible that he managed to get at some intoxicating beverage” (Bernacchi, 1902a).

With no women or children on the expedition, homesickness led to diary writing even amongst the lower deck in the desire to share the experience with loved ones. Sport on ice featured often, mostly football (soccer) and ski running that was good for fitness and camaraderie, but bad for injuries. Scott was incapacitated with a hamstring injury and missed the first sledging attempts due to a downhill skiing accident on 27 February 1902 (Scott, 1905b, Volume 1, p. 228). The diaries and narratives tell only a little about the intellectual landscape on the *Discovery*. The winter series of debates alternated between social concerns of the era and scientific topics. The former covered topics such as women’s rights, Britain’s waning commercial superiority, conscription, sport, spirituality and poetry. The scientific debates covered the existence of an Antarctic continent (or was it an archipelago bound together by a mantle of ice?), whether the ice barrier was afloat or grounded, predictions of weather conditions and the lives of seals and penguins. The debate schedule commenced with two per week, then was reduced to a weekly routine, after which they died out completely. Hodgson concluded that the debates “are now dead, choked with ridicule and drawn to an idiotic length” and with respect to one lecture “Lecture geology-it was a poor affair and as usual Barne, Shackleton and Bernacchi made their characteristic disturbance” (Hodgson, 1901). The positive side, from the point of view of the scientific intellectual landscape, was that “The dialogues had been useful by occasionally producing new ideas, helping to clarify a scientific point, and setting the problems out more clearly” (Baughman, 1999, p. 136). Science lectures were part of the expedition experience and on *Discovery* they were also a means of educating and enthusing the lower deck men about the scientific programs as well as providing survival and navigation skills. This knowledge sharing was no different to that found on modern expeditions, for example, on board the *Aurora Australis* during the 2012 Antarctic shipping season:

> The onboard lecture series has fired up with people providing a half hour presentation on any topic they chose. These presentations are always popular and a good way for us to gain appreciation of the work our fellow passengers do, the wonderful places they have been or the interesting hobbies they may have.
>
> (Australian Antarctic Division, 2012)

The novelty of adventure overcame the young expeditioners and any productive work, whether scientific or logistic, was seen as an achievement as they had no experience by which to benchmark their own productivity. Surviving and working in the polar environment enhances the appetite and the importance of good food to the morale of an overwintering polar party (where a thirty percent increase above the normal ration is required) cannot be overstated (Belanger, 2006, p. 23). Numerous dates for celebrations were recorded on a calendar by Markham to justify festive activities. These included the King’s birthday (coinciding with Bernacchi’s on 8 November), men’s wedding dates, laying of the ship’s keel, the anniversary of the departure of the ship from Britain, Ross's furthest south in 1843, birthdays of the wardroom members and, in line with polar tradition, the mid winter solstice (Markham, n.d.a). That occasion was treated as if it was Christmas, with Moët Chandon champagne, punch and cherry brandy accompanied by treats such as cakes, toffees, ices and puddings (Royds, 2004, p. 142; Savours, 1966, p. 155). Added touches of civilisation included (weekly) hot baths and the arrival of cups of tea brought by the steward to the officers' cabins in the mornings. At times it must have seemed to the wardroom inhabitants that *Discovery* was a gentleman's club on ice, but these are the highlights that get priority in the diaries and narratives. In contrast, Royds' journal, written as a private record for his family only, provides a self-reflective and honest appraisal of many matters during the expedition. His entries around mid winter tell of monotonous discontent, irritability, lethargy and physical discomfort, boredom with lack of culinary variety and constant banter about the poor quality of the tinned fare. "Physically, mentally and perhaps morally, then, we are depressed" (Royds, 2004, p. 143). Scurvy emerged at the end of the first winter amongst the *Discovery* crew and with Scott away from base. Armitage implemented his knowledge gained in the Arctic. The Jackson-Harmsworth expedition had suffered no scurvy and Armitage knew it was most likely a result of copious consumption of fresh polar bear meat. He instituted a diet of fresh seal meat and ensured the cook developed a method to make it palatable, as prior to that time he had been unable to do so.

Another factor that facilitated productive work during winter was an effort to bring civilisation to Antarctica by the provision of light. During the first winter the officers enjoyed brief periods of electric lighting before the windmill was destroyed in a blizzard. The fall back was a cunning design of spirit lamp fed oxygen by a clockwork-driven fan in the base. These "Hitchcock" lamps were acquired during the stay in Cape Town. Candles were in short supply for the second winter but Skelton rigged an acetylene plant and piped gas for lighting to the wardroom cabins. Bernacchi describes the first usage in April 1903 as the second winter approached: “The light is very white + powerful and vastly superior to the lamp light. It will be a great boon throughout the winter if it keeps working we have more than sufficient calcium carbide to last the time” (Bernacchi, 1902c).

Bernacchi is a central figure in the social landscape of the *Discovery*, yet he entered the community at Christchurch after the expedition had been settling socially for six months. His messmates, who may have considered Bernacchi socially inferior due to his informal education, his European heritage, colonial upbringing and his somewhat supercilious air, ridiculed him from time to time. Koettlitz suffered the same, although he had been with the wardroom since the outset, but had the disadvantage of being intrinsically humourless (Skelton, 2004, pp. 178 & 183).

Much of the scientific work could never have been achieved without the contribution of crew members whose labour generally went unacknowledged. The meteorological observations were on a two-hour cycle and they relied on the nightwatchman, a role taken in turn by officers and scientists, making an eleven-day cycle of duty. When the scientific staff was away from Winter Quarters, the full twenty-four hour cycle of meteorological observations became the responsibility of those left behind. Prepared forms for nightwatchmen to note details of auroras during the polar night were printed and Bernacchi was only called out when the displays were outstanding in brightness, colour, form or movement. Hodgson’s collections at sea and on the fringing sea ice relied on assistance with handling the nets, trawls and dredges as well as the occasional whaleboat excursion and seaman Weller assisted Hodgson at his holes in the sea ice during the winters. The ice holes needed to be reopened daily in winter so there was considerable labour before any collecting activity could commence. Sledging journeys that provided data on meteorology and magnetism, as well as glacial, geological and geographic intelligence and specimens, could not have succeeded in most cases without the contribution of crewmen, especially for man hauling the sledges.

## 6.7 *Discovery* released

In total the *Discovery* was locked in the ice at Winter Quarters from March 1902 to February 1904. Scott had no option regarding the second year, as the ship was firmly trapped in ice, miles from the ice edge, where open water met the frozen sea ice. The early 1903 relief ship *Morning* (Captain Colbeck) reported the situation back to London. In controversial circumstances, after Markham's abortive efforts to secure further funding for a second relief expedition, the mission was taken over by the Admiralty who mounted a highly orchestrated relief mission for the navigating season of 1903-04. After news that the *Discovery* was locked in the ice for a further winter, Markham had again approached the government for funds to pay for refit, resupply, then return to Antarctica of the *Morning*. The government was reluctant and the RS distanced itself from the RGS. In Markham's absence the RGS Council struck a deal with the government that included signing over ownership of the *Morning* to the Admiralty, which then took over complete responsibility for the rescue mission. Details of the controversy have been covered in detail by Yelverton (2000, pp. 243-249) and Baughman (1999, pp. 236-244) but it is sufficient to say that this propelled Markham to the nadir of his unpopularity and the Navy went to extreme lengths to make the mission successful. Mill described Markham's efforts as "tactless and hysterical" (Mill, 1903) and Skelton wrote "Mr Balfour said in parliament that his confidence in the two societies had been rudely shaken, but he subsequently recalled that statement as far as the Royal Society was concerned" (Skelton, 2004, p. 193). The whaler *Terra Nova* was purchased and refitted in quick time, manned with a crew of well-salted Dundee whalemen, including Captain McKay, then towed through the Mediterranean and Suez canal route to meet the *Morning* in Hobart in time for the relief in summer 1903-04 (Bryan, 2011, p. 158).

New orders were issued to the effect that if *Discovery* could not be extricated from the ice at Hut Point that summer she was to be abandoned. There were insufficient funds to support another season of work on the ice, and the Navy's generous loan of officers and crew to the expedition had already outstripped expectations. Matters seemed bleak when the *Terra Nova* and *Morning* arrived at the ice edge on 5 January 1904 as twenty miles of ice (32 kilometres) separated the relief ships and the *Discovery*. All the spring sledging expeditions had returned and all efforts were turned to futile sawing of the ice to make a navigable lane. When realisation of the likelihood of abandoning the *Discovery* set in transhipment of all the scientific collections and equipment to the relief ships commenced and scientific activity ceased. McKay's efforts at ramming with the powerful *Terra Nova*, and liberal application of explosives to create fissures in the ice, brought the relief ships closer, so that natural forces of wind and waves could finish the job on 14 February 1904.

The responsibility for the extra cost was of great concern to the RS members who were unsure about the extent of their obligation and who held suspicions about Markham's directions to Scott. William Huggins (1824-1910) wrote to Kempe, the treasurer of the RS:

> Quite Private
> My Dear Treasurer,
> I send you the enclosed letter, and two enclosures from Markham.
> It is satisfactory that the Discovery is safe and has done good work.
> Were <u>not</u> our instructions to Scott clear & definite that he was not to remain a second year, unless unable to extricate himself from the ice?
> I suspected all along that Scott had secret instructions from Markham to remain a second year, notwithstanding official instructions to the contrary.
> Is the R.S. jointly responsible with the RGS for the additional £15,000?
> (Huggins, 1903)

Markham had strongly suggested to Scott that overwintering would lay the foundation to achieve the objectives of exploration:

> The first object will be attained in voyages from the Cape to Melbourne, and from Melbourne across the Pacific to the Falkland Islands. The second object will be secured by penetrating through the pack to the ice barrier. The third will be ensured during winter quarters established as far south as possible.
> But the main object is geographical discovery and the interior of the supposed continent.
>
> (Markham, 1901a)

The magnetic and meteorological programs benefited greatly from the additional opportunity for collecting data as the extended observations from a high-latitude fixed position were desirable. Separating long term secular changes from the daily, seasonal and annual cyclic changes in the magnetic signature was assisted by long-run recordings of the magnetic elements. The same was true for the meteorological data set. The second year of observations helped to determine what conditions were normal for that part of the world. “The second year’s work confirmed the results of the first, and from this point of view are valuable” (Bernacchi, 1938, p. 85).

On the other hand a great deal more coastal exploration, oceanography and magnetic science at sea could have been acquitted if the ship had retreated north for winter. Hodgson spent two years sampling one locality by dredging and trawling through ice holes. His scope was confined to littoral species of the Hut Point locality. Through an error of judgement and in disregard of Bernacchi’s warning (founded on prior Antarctic experience) Scott decided to leave the ship’s boats on the ice when the wagon cloth winter cover was fitted to the ship in autumn 1902. Bernacchi correctly predicted that the boats would be buried in snow and pushed down into the ice floe. Bernacchi noted in mid November 1902 the “Men still endeavouring to rescue boats but is seems almost a hopeless case, they are so deep down & so firmly wedged in the hard ice with water” (Bernacchi, 1902b). This created months of back breaking labour with ice saws and explosives then the carpenter had the task of repairing the damage to the timber afterwards. Unavailability of the boats meant that, even if open water had been nearby, Hodgson would not have had the means for collecting aquatic organisms in McMurdo Sound. His collection, although abundant, was less diverse and smaller than it could have been. Rainbow (2005) describes the collection as “not representative of Antarctica as a whole, since they were taken mainly from shallow water and mostly from McMurdo Sound.”

The location of the ship was fortunate as there was little risk from ice pressure. During the *Southern Cross* expedition ice pressure had pushed up a ridge of ice averaging sixty feet high (~18 metres) that formed against the shoreline (Bernacchi, 1901a, pp. 120-122). The *Discovery* was well protected in the snug cove behind Hut Point but that protection was a factor in preventing the ice break out that was required to release *Discovery*. Bernacchi had sufficient photosensitive magnetogram papers for nearly two years of continuous operation, but why did he have that abundance if only a one-year stay was intended? It may have been a precaution against wastage or unsuccessful procedures, or to allow more fast runs of the drum recorder of the magnetometer to provide an enhanced set of more sensitive (higher resolution) records.

## 6.8 Homeward passage

Following considerable success on sledge journeys through spring and summer of 1903-04, the final operational phase of the expedition commenced. It involved the extrication of the vessel from the ice by the second relief expedition, then the journey that brought them back to England via New Zealand, the southern Pacific Ocean, the Falkland Islands and the Atlantic. Although scientific work was overshadowed by logistics, it did not cease completely, especially for the magneticians. Of all the civilian scientists and officers, Bernacchi had suffered the most demanding routine during internment on ice as he could not share the load of his work. He must have felt great relief when he closed the magnetic hut doors for the last time.

Magnetic work resumed on the northward passage in the Ross Sea and Mulock made a running survey of the hinterland as they travelled. Bernacchi again hoped to get ashore at Wood Bay to take magnetic observations, as it was the closest accessible locality to the magnetic pole but ice was still in the bay, so no landing was possible (Skelton, 2004, p. 200). The ship was swung for deviation (a navigational, not magnetic research function) but this was aborted as the sun became obscured. On 22 February there was a further fright. Water was rising in the bilges to such an extent that the fires had to be extinguished. The pump intakes had become clogged and the pumps were ineffective, even when there was sufficient steam to drive them. The blockages were cleared and a donkey boiler fired up to drive the pumps, thus averting a disaster (Skelton, 2004, p. 200). Cape Adare was revisited on 24 February and the magneticians went ashore to repeat their observations after a two-year interval (Scott, 1905b, Volume 2, pp. 372-378). On 26 February a sounding was made and in the afternoon a trawl was set, but Scott recorded the haul disappointing with "some new species but the catch was not so satisfactory as we could have wished" (Scott, 1905b, Volume 2, p. 383). After replacing the rudder that the carpenter found to have been damaged earlier in the ice, the *Discovery* proceeded west for some modest coastal exploration. The small supply of coal was diminishing, so the achievement was limited to disproving the existence of Wilkes' features: "Ringold's Knoll", "Eld's Peak" and "Reynold's Peak", then improving the chart of the Balleny Islands (Skelton, 2004, p. 202; Royds, 2001, p. 343). One consequence of the ship's fit-out for magnetic work was that the foremast shrouds, made of hemp rather than steel wire, had become slack, posing a risk to the integrity of the standing rig overall (Scott, 1905b, Volume 2, p. 385).

There was a fortnight's lay over at Port Ross in the Auckland Islands, where the ship was painted and cleaned. Koettlitz went botanising and Hodgson beachcombing. Royds' diary for 23 March 1904 gives the scientific program: "Wilson, Mulock and Ferrar took the whaler … and Armitage and Barne took their dip instruments onshore for observations" (Royds, 2001, p. 348). The scientific collections and instruments were transhipped back to *Discovery*. On 29 March it took from 7 a.m. to 11.30 a.m. to swing the ship for deviation under steam, presumably by steaming in a rosette pattern to take readings for compass error at the cardinal and intercardinal points of the compass. A trawl was deployed for over an hour only to find that disappointingly, the net had torn from the frame and there was no catch at all (Royds, 2001, p. 349). The three vessels of the expedition sailed together for Christchurch, arriving to a festive welcome on 1 April. The overwhelming hospitality of Christchurch was a repeat of the outward journey experience. Royds' diary describes a medley of socialising with no reference to ship work or science. The magneticians spent time calibrating instruments with Farr and Skey at the Christchurch observatory that, as the base station and a contributor to the pooled results for the magnetic term days, was an important link in the chain of magnetic data collection. Wilson spent a little time at the Canterbury Museum, but otherwise it was a chance for rest and recreation for scientists and crew after over two years in Antarctica.

The *Discovery* departed Lyttelton Harbour on 10 June 1904 and diary entries for Skelton, Royds and Wilson become spare and infrequent. The ship touched at Punta Arenas on 8 July, then Port Stanley in the Falkland Islands on 12 July. It took all day to swing the ship on 19 July before leaving for England via the Azores. Aside from collecting more seabirds on the way, the only scientific event of note was a visit to see the Prince of Monaco's vessel *Princesse Alice* at Ponta Delgada in the Azores. Royds and Skelton reported it was very well equipped for oceanography with the scientific arrangements on board "most perfect" (Skelton, 2004, p. 221). Wilson wrote: "the ship is simply perfect in its fitting for scientific work" (Savours, 1966, p. 394). Bernacchi acquits the homeward passage in less than one page in his narrative (Bernacchi, 1938, p. 113) and Armitage takes two (Armitage, 1905, pp. 296-297). Neither account mentions any scientific activities after the departure from Hut Point.

Arrival in England brought a reminder to these men of the purpose of the ship and the institutional interest in the expedition. Mostyn Field (1855-1950), Hydrographer at the Admiralty wrote to Longhurst on 1 September 1904 thus:

> Captain Creak, who as President of the Magnetic Sub Committee of the National Antarctic Expedition, having represented to me the necessity of having the "Discovery" swung, and horizontal and vertical force observations made, on her return, before anything is done to alter her sea-going conditions; I request that I may be informed whether "Discovery" will touch at Portsmouth, and, if so, whether it would be convenient for an officer from the Magnetic Department of the Admiralty to carry out the necessary observations there, and that the Captain of "Discovery" may be informed.
>
> (Field, 1904)

## 6.9 Managing data and collections

The prime measure of success of any scientific enterprise is the match between expectations and actual achievements, but the overall success of any expedition may take many years to be fully revealed. The *Discovery* is mostly remembered for its exploratory achievements because they were immediately evident and surpassed expectations. Charts of newly discovered territory, photographs, artwork and the supporting evidence of sledging diaries with navigational observations were sufficient to support the credibility of claims of new territory. Data and collections from Antarctic scientific fieldwork did not rapidly translate into a form useful to either the scientific community, or the general public. When the scientific products of the expedition did appear in the normal forms of scientific publication, the fanfare generated for the arrival home of the expedition had died and the members of the expedition had disbanded. This section describes the handling of the physical and intellectual products of the expedition's scientific program with a focus on the research into terrestrial magnetism.

Under normal circumstances the RS would have been involved in arrangements for the distribution and analysis of collections and data derived from the expedition they co-sponsored, as dissemination of scientific research had always been a core activity of the society (Royal Society, 2010, p. 21). But the RS had withdrawn from involvement after the acrimonious episodes leading to Gregory's resignation, the re-writing of the instructions to favour exploration and Markham's mishandling of the relief expeditions. Initially, the natural history collections would have been shared between the BMNH and Melbourne University, according to Gregory's plan (Gregory, 1900a). With Gregory out of the picture the organising committees failed to plan for the arrival of collections and data, and Markham gained control of their distribution, as he remained the central organising figure in England.

### 6.9.1 Natural history collections

Markham's just-in-time management of the natural history material builds the general picture of how expedition outputs were handled. Murray's engagement as deputy director of the scientific civilian staff included a general agreement that he would be involved in the management of the repatriated natural history materials (Lankester, 1901). In late 1901 Murray sought Markham's approval to hand over the first part of the marine collection, with the zoological and botanical collections from South Trinidad Island, to the trustees of the BMNH after he returned with them from the Cape (Murray 1901f). The pending arrival of the next batch of biological material triggered renewed correspondence. Markham wrote to Kempe of the RS at the end of June 1902, stating that the reports and collections sent from New Zealand were due: "As the reports and collections are now coming home from the *Discovery* it is desirable that there should be agreement between the societies with regard to their disposal…" (Markham, 1902b). Markham then mentions the plankton, phytoplankton, zoological and geological collections that would be entrusted to Murray according to the minute appointing him, but mentions that neither he, the civilian scientific staff or Scott wanted the collections to be in Murray's hands (Markham, 1902b). The responsibility for the expense of analysis and publication is notably absent from the early correspondence, but after the first relief expedition of early 1903, Markham wrote to Huggins to convey the news that the British Museum and the treasury had made provision for "publication of the results of the Antarctic expedition as regards natural history and geology" in their budget estimates (Markham, 1903a).

### 6.9.2 Magnetic data

The case of the magnetic data was more complicated than the natural history collections. Candidates for receipt, reduction, analysis and publication of the magnetic results could have been either the National Physical Laboratory at Kew, the Admiralty Compass department (that had been under the superintendence of Creak until June 1901), the Admiralty Hydrography department under the directorship of Wharton or the RS itself. All these institutions sponsored the expedition at some level and had some claim on the intellectual property generated from the expedition's magnetic program. Adding to the complexity was the overlap between the potential utility of results to navigation (commercial or naval) on one hand, and to pure scientific research on the other. The Admiralty, through its extensive support to the expedition (during shipbuilding, by lending instruments, by lending officers and crew, by refitting *Discovery* and supplying materials at Cape Town, and finally by mounting the *Terra Nova* relief expedition) may have felt a majority right of ownership of the intellectual property. The RS had been a sponsor prior to the RN involvement and although the RS did not stay deeply engaged for the duration of the expedition, its contribution was significant. A complicating factor was the expectation of additional data from the *Gauss* under Drygalski and a number of cooperating terrestrial observatories. It was unclear who had the prerogative to decide where the magnetic data should be sent, but Markham was in control. While Gregory was still the scientific director he stated the view that the "scientific results be placed in the hands of the Executive Committee and published as it directs, under the editorship of, say one member of the Committee, and one member of the Scientific staff" (Gregory, 1900a).

The first data was sent from Cape Town with Armitage's report of the difficulties with the Lloyd-Creak instrument. Markham commenced making arrangements for the whole of the data and collections and, with respect to the magnetic data:

> It is proposed, subject to alterations or other proposals made by the President and Council of the Royal Society that:
> 1 The magnetic report & observations be referred to the Hydrographer and Captain Creak with a request that the two councils may be furnished with a report upon them.
> (Markham, n.d.f)

Huggins of the RS responded with agreement that the observations should be sent to Wharton, the hydrographer (Huggins, 1901). Creak had previously reviewed the data and nominated what he considered to be useful results, and: "As the Hydrographer has so thoroughly supported everything in the way of supplying the magnetic & other instruments to the 'Discovery'… the observations marked in blue pencil should be sent to his department as being immediately useful." He further suggested the greater part of the observations: "are tentative ones for practice & not much use beyond showing how the observers are handling the instruments" (Creak, 1901a). Even though Creak had retired, he had access to data initially and filtered the material passed on to Wharton, via Markham. Wharton sent a polite, though possibly sarcastic letter to Markham, requesting the full data set:

> We of course hope to have all observations … made by the Discovery, as it is mainly by this department that they will be utilized for general benefit. I hope what I have received is only an instalment as they are of little value… I understand that

> observations were obtained on the passage also. These are of course the interesting ones to us so far, & should be of great value. I hope you can send them.
>
> (Wharton, 1901)

Creak's assessment of the observations made at the rifle range on Red Hill behind the Simon's Town naval base were negative: "some work signed Morrison was defective the observations not being completed on account of darkness coming on. The Fox observations are for the most part very bad & I fear they will turn out useless" (Creak, 1901c). Markham must have agreed to Wharton's request. In early 1902, when the cases of natural history specimens were beginning to arrive he wrote: "The magnetic observations have been sent to Captain Creak, eventually to go to the Hydrographer" (Markham, 1902a). Markham may have obstructed Wharton's access to the data, as payback for Wharton's earlier opposition to the appointment of Scott as commander.

Later in 1902 Markham made further arrangements: "Magnetic observations and report on soundings to the hydrographer, also determinations of specific gravity of sea water. Meteorological observations to the meteorological office. Atmospheric carbonic anhydride determinations to Professor Letts" (Markham, 1902b). Note that throughout all this wrangling over the fate of the observations there was no mention of involvement by the National Physical Laboratory, a key institution working on terrestrial magnetism.

Bernacchi sent home material with the *Morning* when it became apparent on 26 February 1903 that the *Discovery* would be interred in ice for another year.

> Am preparing 12 magnetograms to send home. One for each month of the year 1902-1903 being one of the least disturbed + most typical. Also sending data for reduction of the curves should this become necessary before I return home.
>
> (Bernacchi, 1902c)

Markham's letter to Bernacchi towards the end of the expedition refers to the magnetograms and adds a new twist:

> The specimens sent home by the <u>Morning</u> I sent to the hydrographer provisionally. But it will be for Captain Scott to decide what is best to be done with the whole of your invaluable collection of magnetic observations, in order to ensure that they are dealt with to the greatest possible advantage for science; he will no doubt consult with you on the subject.
>
> (Markham, 1903b)

This was disingenuous, but not out of character, as Markham had already completed arrangements. The magnetic data finally went to both the Admiralty and the National Physical Laboratory and it was the RS who published the two volumes of official scientific reports. A magnetic committee had been established by the RS including the scientists Chree and Glazebrook, the Admiralty compass experts Creak and Louis Chetwynd (1866-1914) and others, then a sum of £300 was voted towards reduction and publication of the results (Royal Society, 1904). Chetwynd of the Hydrographic Department of the Admiralty was the lead author of the magnetic section of the *Physical Observations* volume, while Chree of the National Physical Laboratory was responsible for most of the *Magnetic Observations* volume. For his contribution Chetwynd explained: “All the available information has been through my hands, and the reduction of the observations has been made by me and checked.” The values from the magnetograms were tabulated at laboratory under Chree’s superintendence (Chetwynd, 1908, p. 134).

### 6.9.3 Bernacchi’s post-expedition contribution

Bernacchi expected to be employed on reduction and analysis of his own data:

> I hear, that on our return, we shall be employed as sub-editors in publishing the scientific work. My own work, which includes at the present moment a year’s record with the Eschenhagen instruments – seismograph, pendulums, Auroral observation and atmosphere electricity, will take two years at least to bring out.
>
> (Bernacchi, 1903b)

During the winter of 1903 there was a discussion in the wardroom amongst the scientists about the involvement of the observers and collectors in the working up and publication of results from the expedition (Ferrar, 1903). Creak was in favour of Armitage and Bernacchi being retained to work up their own data (Creak, 1903). Scott wrote to Bernacchi indicating the prospects of post-expedition employment were good: “Of course you ought to be employed for the whole show” (Scott, 1904). After the *Discovery* was sold to the Hudson Bay Company, Scott again reassured Bernacchi: “There will be a decent surplus now that the ship is sold and I’ve already stated that I think it ought to be diverted to the scientific work and primarily for the purpose of renumeration of the scientific staff …” (Scott, n.d.b). In reality Scott had no influence over this matter.

Bernacchi worked at the Observatory Department of the National Physical Laboratory assisting with the reduction of his “Differential magnetic work” (Geikie, 1908, p. v). He knew what was required after his previous employment at the RS working on the *Southern Cross* magnetic data and preparations for publication. Glazebrook at the laboratory had offered him: “£30 per month for two or three months” (Bernacchi, 1904) and he was eventually employed for six months, mostly scouring his daily records and the register of watch and chronometer rates (errors) to determine the exact start and stop times of the magnetograms. This did not represent ownership of the intellectual property of that material as the results were not published under his name, although his involvement was acknowledged.

### 6.9.4 Data from collaborating observatories

Data from collaborating observatories was slow to arrive. Data from Cape Town and Christchurch was the most critical, being germane to the calibration of the ship’s magnetic instruments and as Christchurch was the magnetic base station for the expedition. There was an ongoing round of correspondence from 1902 to 1904 between Markham, Wharton, Creak, Farr and Skey about the handling of the data from Christchurch and seeking clarification of the details of exactly where the magnetic observations were made on the ship during the first swing at Lyttelton. It was unclear whether they were taken on the bridge using the azimuth navigational compass, or in the ship's magnetic observatory at the Fox position where the Lloyd-Creak circle was mounted (British National Antarctic Expedition, n.d.a). The Christchurch observations were reduced locally and the final data arrived shortly before publication of the *Physical Observations* report, so it was included hastily.

Data finally appeared in the scientific reports of the expedition from Greenwich, Kew, Falmouth, Pola (Austria), Colaba (Bombay), Mauritius and Christchurch. All except two are from the northern hemisphere, so global coverage was not comprehensive. None appeared from Melbourne, Cape Town, Staten Island (Isla de los Estados), Potsdam (Eschenhagen's home observatory) or from either the German base station on Kerguelen, or the *Gauss* itself. Data from Bruce's *Scotia* expedition is included in the *Physical Observations* report (Royal Society, 1908, pp. 181-190) but it was not intergrated with data from other sources.

## 6.10 Scientific outputs

### 6.10.1 Lectures and journal articles

The ship was welcomed home to the East India Docks with a splendid banquet in a quayside warehouse on 16 September 1904. Markham ensured that the media were well represented, reserving many seats for journalists (Markham, 1904b). Public speeches and lectures about the expedition's achievements commenced here for the British public. Newspaper reports generally praised the work of the expedition, although one critical commentary stated:

> There is no system to it; the thing gets done in a haphazard way, chiefly by individual initiative and enterprise. That is the way we do most things. It is a way that has great drawbacks and defects, but still we 'get there'.... *Discovery* is a

> case in point, and quite in the old style. It has owed nothing to system, everything to individual initiative, capacity and liberality.
>
> (Arrival of the *Discovery* in London, 1904)

Markham arranged a public lecture by Scott at the Albert Hall, delivered on 7 November 1904 where seven thousand guests heard the message of geographical success and solid performance of the scientific staff (Fiennes, 2003, p. 134). Within the eighty-three pages of notes for the lecture, magnetic studies are barely mentioned, and then only the land-based observing is cited. No results or difficulties encountered making observations at sea were mentioned, nor was there any new information about magnetic science, as one might expect in a lecture for general consumption. Bernacchi's work during the barrier journey is also mentioned briefly, but as an example of the hardship facing sledge travellers, not as a reference to the magnetic work (Scott, n.d.a). Larmor of the RS had written to Markham just prior to this cautioning that public speaking engagements of this sort risked premature release of scientifically important and interesting results in a maner that was unfair to the expedition scientists. Markham's handwriting on the letter indicates "no notice taken" (Larmor, 1904).

Bernacchi gave a noteworthy lecture to the RGS on 8 May 1905, where he described the general trends of the magnetic and other physical science outcomes. This is the best synoptic account of the outcomes of the physical science research on *Discovery* as it was formulated for an intelligent, but not necessarily scientific audience. It was recorded in the *Geographical Journal* and was not confused by the onerous detail of the scientific reports (Bernacchi, 1905). He opened the paper with consideration of the scientific value of the work and the absolute necessity of observations in the Antarctic, then advised his awareness that theory in terrestrial magnetism could only be developed after comprehensive Antarctic observations of magnetic constants and changes (Bernacchi, 1905). He focused on the magnetic work at Winter Quarters and on the sledge journeys, then acknowledged that there was still a mass of data to be analysed, including the contributions from collaborating observatories. Bernacchi made it clear that although data reduction had commenced, he was reporting his general observations of a preliminary nature and these should be viewed with considerable reserve. He mentioned the agreement for synchronous observing for term days and term hours. Creak was in the audience and, in the post-lecture discussion, noted the omission of the observations made at sea using his instrument. “I notice that the sea observations are excluded from this paper, but I may incidentally remark that a series of ship observations, which are possibly of great value, was taken after the ice-pack was entered” (Creak, 1905).

Journal articles were an additional means of reporting scientific results. Although the primary method of reporting the outcomes of scientific work on *Discovery* was via the official reports formatted as compilations of research papers, most news of the *Discovery* expedition was circulated initially in Scott’s summaries of proceedings in the *Geographical Journal*, the organ of the RGS. The journal had nine pre-expedition articles followed by sixteen progress reports published during the course of the expedition.

Only two articles could be considered post-expedition scientific reports on terrestrial magnetism, and both were reports of lectures by Bernacchi rather than scholarly papers. First was coverage of Bernacchi’s lecture at the RGS on the preliminary physical results (Bernacchi, 1905). The other appeared in the premier journal for magnetic science of the period, the American Geophysical Union’s *Terrestrial Magnetism and Atmospheric Electricity* that reported a lecture by Bernacchi to the British Association for the Advancement of Science (American Geophysical Union, 1908). One pre-expedition and two progress-report style articles appeared in *Nature*, and *the Scottish Geographical Magazine* contained seven progress-report style articles. Chree was a frequent contributor to *Philosophical Transactions of the Royal Society*, but his articles concerned the work at Kew, not the Antarctic expeditions. The synchrony of magnetic storms across the globe was a topic of ongoing and vigorous debate between Chree and Bauer in the pages of *Nature* during 1910 and 1911, but no references to the Antarctic expeditions appeared in the public interchange.

### 6.10.2 Scientific reports

Official scientific reports were the primary means of publishing results from expeditions at the turn of the twentieth century. From *Discovery* six volumes of natural history reports (Vol. I, Geology (Field-Geology, Petrography); Vol. II, Zoology (Vertebrata, Mollusca, Crustacea); Vol. III, Zoology and Botany (Invertebrata, Marine Algae, Musci); Vol. IV. Zoology (Various Invertebrata); Vol. V, Zoology and Botany; Vol. VI, Zoology and Botany) were published by the BMNH between 1907 and 1912. An album of sketches and photographs with a portfolio of panoramic views published in 1908 was of more general interest and supported the claims regarding new territory. The RS published the first volume of meteorological results in 1908 then the second volume followed in 1913 (Rosove, 2001, pp. 345-350).

The *Physical Observations* was the first scientific report published from the expedition's physical research (Royal Society, 1908). The contributors were (George) Darwin (1845-1912), Milne, Chree, Chetwynd and Bernacchi, who made a significant contribution with introductions to the magnetic, auroral and pendulum and seismic sections. Its companion volume, *Magnetic Observations,* was released the following year, 1909. As a pair they described conditions and methods of operation of the physical researches and, for the land observations, an almost day-by-day account of the movements of the magnetograph pens. The first volume also includes tidal observations, pendulum observations, the results of the seismic surveys, descriptions and Wilson's illustrations of auroras, then magnetic data and analysis from the ocean passages, swinging the ship and the overland sledge journeys. Some preliminary comments about the Winter Quarters observatory data appear in this volume, but they are mostly dealt with in the second volume, *Magnetic Observations* (Royal Society, 1909).

The magnetic section of *Physical Observations* commences with a preliminary report of some of the absolute (Kew magnetometer) data from Winter Quarters. Observations were generally performed each month or six weeks to “afford the means of standardising the values indicated by the photographic curves” from the Eschenhagen magnetograph (Chetwynd, 1908, p. 134). The only results considered reliable enough to report were between December 1902 and January 1903, and of those ten observations, five were excluded from the analysis. It was determined that “... many of the absolute results to determine the magnetic axis are unreliable” (Chetwynd, 1908, pp. 138-139). The mirror on the end of the swinging magnet was out of alignment and the instrument was out of adjustment in other respects. It was necessary to assume that the azimuth mark adjacent to the absolute hut that served as the reference point for alignment of true north had not shifted during the two years of observations.

The *Physical Observations* report also contains results of magnetic observations on some of the away-from-base sledge journeys. The data obtained during Bernacchi’s spring 1903 Barrier sledge journey is found at tables VIII and IX on page 142. This journey and Armitage’s western journey of summer 1902-03 were the only overland journeys where specialised instruments were used for magnetic observing. The data obtained contributed to the Chart III (Plate 19) that shows the lines of equal inclination for the Ross Sea locality. Declinations were recorded with the aid of a prismatic compass, probably the same instrument on display at Canterbury Museum, Christchurch, shown in Image 10. The declination data from other sledge journeys, including the southern journey of Scott, Wilson and Shackleton (also taken using prismatic compasses) contributed to Chart I (Plate 17) that shows lines of equal magnetic declination (isogons) and Chart II (Plate 18), showing the position of the South Magnetic Pole (Royal Society, 1908, following p. 156). These charts are confined to the Ross Sea locality.


Image 10: Bernacchi's prismatic compass on display in Canterbury Museum, Christchurch (author's photo).

The most striking feature of the *Physical Observations* report is that almost all of the at-sea observations were never reported or discussed, and their omission goes unexplained! Results for magnetic force at sea are non-existent. Results for inclination (dip) at sea are only reported for a handful of observations on the homeward journey and only at high latitudes. Commencing on 20 February 1904 there are three readings from the Lloyd-Creak circle (probably Bernacchi's first experience with the instrument on a moving vessel) then a further seven observations were made with the Fox circle, ending on 4 March. These are observations from inside the line of pack ice and taken when sea conditions would have been moderate (Royal Society, 1908, p. 149). Compensation for deviation is discussed and results for the swings of the ship at Wood Bay, Auckland Islands, Lyttelton, Falkland Islands and Spithead are reported at Table XIV (p. 148). The data for Lyttelton was ultimately rejected due to inconsistencies. A "remarkable difference" in results for deviation was found between the 1902 and the 1904 ship swings in Wood Bay. This indicated "…the magnetic conditions at the compass position in the observing cabin had, in the interval, undergone a very great change; possibly this change was due to alterations in the stowage of stores in the ship" (Chetwynd, 1908, pp. 147-148). This factor added uncertainty to all other at-sea observations as the tinned provisions were continually removed for consumption. Armigate noted also that ferrous objects such as a birdcage, a rifle and cookwear were sometimes left adjacent to the magnetic observatory (Armitage, 1905, p. 303).

The daily observations for variation (=declination) are tabulated for the voyage at Table XVI (pp. 150-155). These only require knowledge of the ship's deviation, (the compensation required to account for the influence of ferrous materials in the ship according to its heading), time, location and a solar azimuth reading to determine geographic or true north and a ship's compass for determination. In short, this is data that could have been collected by any ship, and in the days of sail it would have been routinely recorded and no magnetic laboratory or specialised instruments were required. The contribution of the vessel as a floating magnetic laboratory paid no dividends.

Section XIV compares declination values in the Ross Sea region against data from Ross's campaign and concludes there was a long-term trend of declination increasing on average of 23' per year. Between 1902 and 1904 the average was calculated to be a *decrease* of 26'. This unlikely result is not discussed. Likewise there is no explanation for the average annual change in inclination since 1841, being -1' whereas the average from the two years of *Discovery's* stay in the ice is -6.7'. The magnetic pole appeared to have moved about two hundred geographical miles towards the north and slightly east (Chetwynd, 1908, p. 157). Data from contributing observatories for the synchronous observing arrangements is covered in a section that covers hourly values for declination, horizontal force and vertical force. No acknowledgement is made here of the German expedition, or the *Gauss* (Chetwynd, 1908, p. 159). This section is comprised of data sets with no interpretation or discussion. The final section in this volume is a discussion by Chree of the magnetic observations on Bruce's *Scotia* expedition. This is a surprise as Markham had unequivocally rejected Bruce's offer of cooperation in magnetic observing before either expedition embarked.

The second physics volume is the *Magnetic Observations* report, a lengthy technical volume reporting the observations made at Winter Quarters and representing the bulk of achievement in the magnetic science program (Royal Society, 1909). Bernacchi again provided an introduction on the arrangements of the observatory and instruments and aside from this, the report is almost entirely the work of Chree. Over sixty pages of tables of hourly data for declination, horizontal force and vertical force observations between 1 March 1902 and January 1904 form the core of the report and there are some discontinuous sections after September 1903 due to shortage of papers for the Eschenhagen magnetograph. Many examples of the actual magnetograms (the traces from the Eschenhagen instrument) are provided in forty-three plates at the end of the volume to illustrate points made in the body of text. The data is dissected and described in minute detail and in technical language for the consumption of scientists. Discussion is mostly confined to descriptions of phenomena represented in the data, such as magnetically quiet or magnetically disturbed days, diurnal inequalities in the magnetic elements and Fourier coefficients, representing waves or long pulses (about twenty-four hour) in the magnetic signature. Cyclic (diurnal and seasonal) and the non-cyclic (secular) changes in terrestrial magnetic elements of declination, horizontal force and vertical force are the themes throughout. Note that there are three magnetic seasons: midsummer, midwinter and the equinoxes. Absolute daily ranges get special attention, as do the term hour records, results from the solar eclipse, magnetically highly disturbed days (magnetic storms) and records compiled from the cooperating observatories. Unfortunately there is little speculation on how the data fits with theory.

Chree's opening statement in his *Historical Note* that: "under these circumstances few serious mistakes were discovered" is at odds with evidence revealed during this research that detected many errors and inconsistent results, and significant amounts of data were discarded (Royal Society, 1909, p. 5). The following material shows there were numerous difficulties, and that a great amount of data was either discarded, or reported with cautionary notes being considered unreliable. Chree opens his discussion of observations by noting that the Eschenhagen magnetometer arrived late in England giving no time for staff of the National Physical Laboratory to become familiar with it. One consequence was the quartz filaments for the suspension of the horizontal-force variometer magnets that were sent to Antarctica were too fine, and therefore too sensitive for observations close to the magnetic pole. Although Bernacchi reported that the Eschenhagen apparatus operated continuously for two years, it did not necessarily produce reliable traces. If the lamp on the side of the apparatus was disturbed when refilling the oil tank and trimming the wick the traces were displaced. "The number of ways in which the traces might have their positions changed on the sheet was very large, while the instruments were so light that a slight touch might cause movement" (Royal Society, 1909, p. 73). From time to time in the cold the oil would not burn well, producing only a feeble light that failed to register on the photosensitive paper. In his discussion of the absolute observations Chree refers back to Chetwynd's note in the *Physical Observations* that the number of absolute observations available was "really very small" (Royal Society, 1909, p. 74). Inability to correlate the traces from the magnetograph against absolute standards diminished their value.

Chree implies instrumental error and exonerates Bernacchi's technique. "If the absolute observations had been faulty-a circumstance improbable in view of Mr Bernacchi's experience-this would have shown itself through irregularity in the values given by the individual observations for the moment of [magnet] 25A." Many days worth of the vertical force trace were lost as "In some cases the magnet was evidently stuck" meaning that many days records were rejected. He further states: "In some months a good many days' traces which were complete were omitted because there was reason to doubt whether the instrument was working" (Royal Society, 1909, p. 102). With respect to the daily ranges for declination and horizontal force, Chree stated: "the number of days when the record was incomplete was so considerable, and the cause was so frequently due to the limits of registration being exceeded, especially in Summer…" indicating that the traces frequently went off the scale on the 20 cm. wide magnetogram (Royal Society, 1909, p. 131). On 31 December 1902 Bernacchi inadvertently reversed the direction of a magnet in the Vertical force variometer when he relocated it to compensate for the influence of a large summer temperature range within the hut. This affected the sign of 1903 records. This was yet another source of anomalous results that led Chree to fear: "that nothing could be made of the vertical force records" (Royal Society, 1909, p. 76).

Chree discusses secular (non-cyclic) change in the magnetic elements in detail in chapter II. He concludes that if the figures are a "true measure of secular change, the natural inference is that the south magnetic Pole is receding from Winter Quarters-*i.e.*, is moving northwards-at a rapid rate." Then: "the declination figures are no less remarkable" and "Such a phenomenon seems hardly credible, and one cannot but suspect some instrumental source of error" (Royal Society, 1909, p 81). Chree concludes discussion of the force: "It is obvious from what has already been stated that the Vertical-Force base lines for individual months are affected by uncertainties which would render any deductions as to secular change or annual inequality of very problematical value" (Royal Society, 1909, p. 83). Chree does draw some conclusions from trends in the data. Equinoctial months are much less magnetically disturbed than midsummer (Royal Society, 1909, p. 138). Daily maxima for declination tend to be clustered around 9 a.m. and minima around 6.30 p.m. indicating a single daily oscillation at Winter Quarters throughout the year (Royal Society, 1909, p. 101).

Analysis of the amplitude and direction of the diurnal inequalities indicated a change in the direction of secular change for declination might be looming. Similar data trends had been found at Kew and Chree states: “Thus here again we appear on the threshold of a most suggestive line of inquiry” (Royal Society, 1909, p. 101). Chree enters into a little speculation about electrical currents in the upper atmospher and offers the suggestion that if diurnal inequality is due to atmospheric electricity, then the effect should be the same at the magnetic pole as it was at Winter Quarters. Following that premise, and connecting it with the trend that inclination was greatest “about 4 or 5 a.m. in the morning” and was “lowest from 2 to 3 p.m.” it implies that the magnetic pole oscillated daily, being closest to Winter Quarters early in the morning and furthest from it in the afternoon (Royal Society, 1909, p. 103). Chree provides advice to observers of the next Antarctic expeditions to study annual inequality in particular, to confirm his interpretation that the location of the magnetic pole oscillates annually (Royal Society, 1909, p. 138). There is no speculation on a cause of these phenomena and he states “even in Europe two years is too short a period to give results of a really representative character for the annual inequality of magnetic elements” (Royal Society, 1909, p. 81).

The analysis of data for Fourier coefficients, that indicate subliminal wave patterns in the changes of the magnetic elements, opens with a cautionary note that differences in values may owe as much to “accidental” disturbances as any real differences in magnetic conditions. The uncertainty over the “accidental” disturbances make it: “by no means clear how best to interpret the figures.” Chree concludes: “the 24-hour Fourier wave is largely dominant” and then seems to contradict himself saying that, although there are only two years of data from the Antarctic: “they present features which can hardly be regarded as the result of accident, and which seem of much interest" (Royal Society, 1909, pp. 117-129). The Swedish researcher, Birkeland whose auroral researches were the most advanced in the discipline, wrote the lengthy discussion comparing his Arctic results against the *Discovery's* Antarctic research. This was not a planned collaboration, just a post expedition overview made possible by the congruence of material becoming available.

Outcomes related to global synchronous observations are of special interest and are detailed below at Section 7.1.10. but a separate discussion relates data from combined observatories showing the onset of a magnetic storm coincident with a volcanic eruption of Mount Pelée. Chree suggests a theory whereby the Earth is composed of a nucleus surrounded by a shell of material of different permeability, then an outer, non-magnetic crust of unknown thickness, but he concludes that the coincidence between the eruption and the magnetic storm was pure coincidence (Royal Society, 1909, pp. 171-180). He discounts the action of the Sun as the cause of disturbances, arguing that different observatories would encounter the magnetic storm at different times if it were the case but the evidence shows that disturbances are closely synchronised between the Antarctic observations and those elsewhere. Chree was considering ideas that are building blocks of current theories of terrestrial magnetism, but rejected the most promising lines of inquiry. Scientists now consider about ninety percent of the earth's magnetic field is derived from the ferrous molten core that remains stable and whose minor variations are measured in years. A smaller, rapidly moving magnetic field is generated in the upper atmosphere and the changes are measured in minutes and seconds (Belanger, 2006, pp. 267-268).

These published reports are the most concise analysis of the data from the *Discovery* and the cooperating observatories, so any new theory, or confirmation of existing theory should be evident here. None appear, although some new lines for future enquiry are suggested. The reports failed to provide any synoptic overviews of the meaning of results and few general conclusions or insights are drawn from the data. The last word on theory is found in Chree's discussion of disturbances: "It must be admitted that our direct knowledge of the Earth's magnetic quality is very slight…How the Earth comes to be a magnet is a mystery…the source of the Earth's magnetism is almost entirely internal" (Royal Society, 1909, p. 171).

The profession of science communicator did not exist in 1909 and the scientific reports were written for the information of other scientists, not the general public, media or sponsors. After reading the *Physical Observations* report Scott wrote to Bernacchi asking for interpretation of Chree's style: "I am a bit disappointed with Chree's contribution-it is very analytical as concerning the curves but I could wish there was more treatment of results" (Scott, 1908a). Scott probably thought the same about the contents of the second volume.

The *Discovery* expedition was long forgotten when the *Physical Observations* and *Magnetic Observations* volumes were published. Polar news at the time centred on claims of the attainment of the North Pole by both Robert E. Peary (1856-1920) and Frederick Cook (1865-1940) and the success of Shackleton's *Nimrod* expedition. Scott was commencing his campaign to procure funding for the *Terra Nova* and probably preferred that there was no scrutiny of the quotient of scientific output compared to cost for the *Discovery.*

### 6.10.3 Cartography

There are various classes of chart or map produced as outputs from the *Discovery* expedition. Topographic maps and charts documenting new territory found during coastal exploration and sledge journeys are the most common cartographic product. Replacement of Shackleton by Mulock was an inspired decision as he was a cartographer of skill. His first chart published in the *Geographical Journal* shows the extent of new territory discovered with the ship's track and the routes of all significant sledging journeys shown in detail (Mulock, 1904). Mulock's charts show the first ever surveys of Ross Island, the Western Mountains, the Polar Plateau and the mountain range fringing the western coast of the Ross Sea south to 82° S. Some new coastline was surveyed at the far eastern extent of the Great Ice Barrier where King George VII Land was discovered. A folio of six charts by Mulock was published in 1908 as a supplementary publication from the expedition. They show the geographical features and tracks of explorations, but no magnetic charts were included in the set (Mulock, 1908). Skelton lamented the time wasted fabricating the plane table and sledgemeters, essential items of equipment for surveying that should have been brought with the expedition (Skelton, 204, p. 111). A plane table was also on Gregory's list of necessary equipment (Gregory, 1900a). The reliability of Ferrar's geological contribution was brought into question by the annotations by Griffith Taylor (1880-1963), who, during the *Terra Nova* expedition: " marked all his *Discovery* maps 'Wrong'" (Bull & Wright, 1993, p. 152).

There is one obscure error on Mulock's chart associated with magnetic conditions. On 22 November 1903 Scott's party crossed the line between the geographic and magnetic poles, where the magnetic declination (or variation) was 180° and the south geographic pole appeared to be due north by the compass.

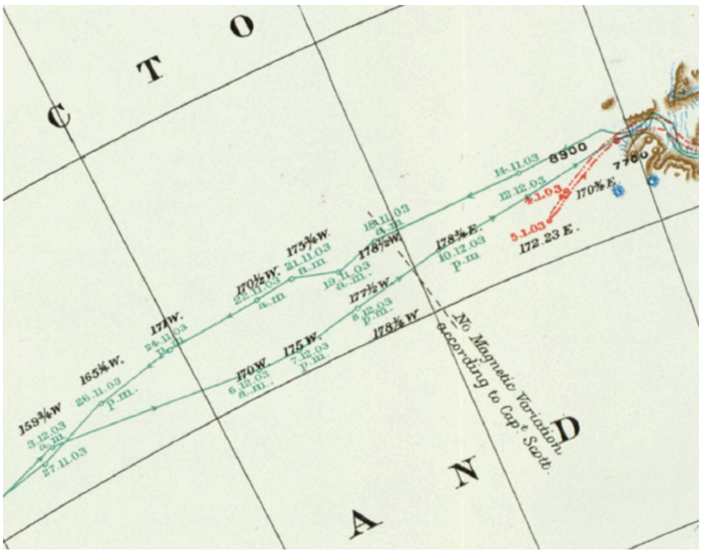


Figure 11: Detail of the chart showing the track of Scott's 1903 western plateau journey (Mulock, 1904).

This point is incorrectly marked on the chart as a point of “no magnetic variation” rather than a point of 180° of variation as shown at Figure 11 (Mulock, 1908).

A second category of chart is found in the scientific reports, where three plates show the magnetic elements of declination and inclination, as well as the location of the magnetic pole in the Ross Sea region at the time of the expedition. Figure 9, shown at Section 6.3 is an example. They were the only outputs from the expedition of potential value to mariners, but they were buried in the scientific reports. In practice they were of little commercial value being scientific, not navigational as there were no commercial or strategic voyages to the locality, other than Antarctic exploratory voyages. A further point is that magnetic data are stale by the time of publication, especially in the region close to the magnetic pole where there is constant change in the magnetic signature revealed by the isogons connected to it.

A third category of charts was produced specifically for the use of mariners. Although Markham had promised that *Discovery* would provide new magnetic data leading to production of sea charts of utility to mariners, none were produced. The United Kingdom Hydrographic Office (UKHO) published editions of magnetic variation for the world (chart series 2598) from time to time. The editions relevant to the *Discovery* were those from 1895, 1907 and 1912 and none were published between these versions. The UKHO did not keep records of the provenance of data for their charts prior to 1913 (Dr Adrian Webb, Archive Services Manager, UKHO, personal communication, 26 July 2012) so there is no traceable link between the data from *Discovery* and improvements in the regular series of charts. The 1895 edition shows isogons above 60° S at 1° intervals whereas the next (1907) edition, published after the *Discovery* data became available, shows isogons above 60° S at 10° intervals (Figure 12). This means that even if data from *Discovery* had been incorporated into the newer edition, the resolution and therefore the value to high latitude mariners had actually diminished since the 1895 edition. In any event, competent navigators in the days of sail kept a watch-by-watch check on the variation as they have done since latitude determination by chronometer became possible, so magnetic charts were unnecessary. Prior to that, magnetic charts were an extra check for mariners determining longitude by dead reckoning.

Markham's promise that *Discovery* would provide new magnetic data leading to production of sea charts of utility to mariners was not delivered. Charts of ice concentration in mid to high southern latitudes would have been of more utility to the wool, grain and nitrate trading vessels of the southern oceans.

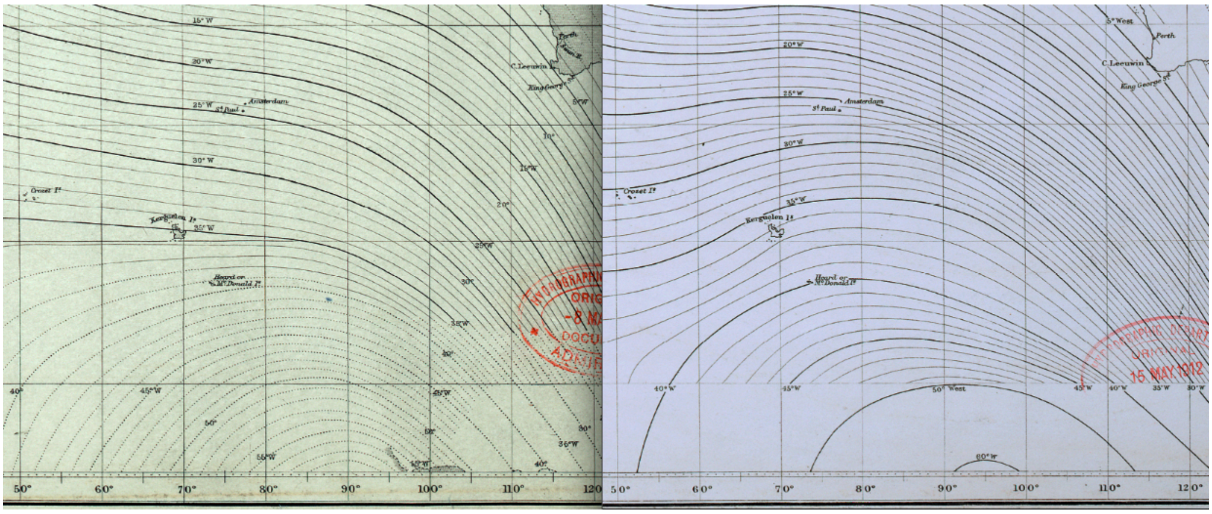


Figure 12: Comparison of detail from UKHO Magnetic Variation Chart series #2598, 1895 edition (left) and 1907 edition (right).

### 6.10.4 Narratives

As with most expeditions, members were bound to not circulate personal accounts until a specified period after the official version of events was published. Scott's narrative, *Voyage of 'Discovery'* sold well. It provided an exciting account of the operations and detailed Scott's southward trek, the jewel in the crown of the expedition and other sledge journeys. These were the first ever incursions towards the interior of the continent and the significance was not lost on the reading public. In terms of new territory discovered and the attainment of a new furthest south, the *Discovery* was far more successful than Drygalski's *Gauss*, Bruce's *Scotia*, Nordenskjöld's *Antarctic*, Borchgrevink's *Southern Cross* and de Gerlache's *Belgica*.

Access to the narrative restored national pride and, with many quality photographs, brought images of new landscapes and creatures into lounge rooms. Scott managed to weave some of the scientific elements of the expedition into the narrative, but it generally focused on day-by-day events and the main sledge journeys.

Armitage wrote a very readable narrative, *Two Years in the Antarctic*, which provided significantly more detail about the magnetic science research than Scott's own account (Armitage, 1905). This account was published slightly before Scott's, contrary to the terms of engagement, but there was no practical means for Scott or Markham to prevent this. Armitage gave a good account of the reasons for undertaking the magnetic research but with a focus on the maritime, not the theoretical aspects of the program. His *Appendix B, Terrestrial Magnetism* discussed the magnetic science program and gave the reader a good synopsis of the operations and challenges of the work. His closing comments about the way in which the data gathered from the expedition would: "enable those who go down to the sea in ships to navigate with a greater measure of confidence and safety those waters that wash the shores of our southern possessions and South America" seems like hyperbole in the light of his acknowledged difficulties taking observations at sea (Armitage, 1905, pp. 301-304). His predictions were baseless as the anticipated magnetic charts for mariners derived specifically from the efforts of the *Discovery* never eventuated.

Bernacchi requested permission from Markham to publish a narrative shortly after the expedition returned but was refused: "no one in the 'Discovery' can publish anything in a journal or magazine until after Scott's book is out" (Markham, 1904a). *Saga of the Discovery* is his history of the ship that was finally published in 1938. It was largely developed from Bernacchi's journals and correspondence and provided a vehicle for the author to tell his version of the events. He mused on certain topics with the benefit of hindsight and in the knowledge that most of the protagonists had passed away, but does not describe the magnetic research in detail. Lambert suggests the narratives of the British Arctic expeditions of the nineteenth century were published as a means to demonstrate to the world that the results were British and supported the notion of “Imperial exploration” (Lambert, 2009, p. 36). The narratives from the *Discovery* expedition are in the same mould.

Chapter four provided the historical contexts and the background to the preparations of the voyage to the ice, including the state of knowledge in the discipline of terrestrial magnetism and the importance of patronage and funding. Planning for the construction of the vessel and the overall expedition program was discussed there in the context of the anticipated research into terrestrial magnetism. Chapter five described the scientific practices undertaken in the magnetic program on the outward passage to New Zealand and this chapter has investigated the key elements of the practice of terrestrial magnetic science on the ice by the *Discovery's* physicist, Bernacchi, and the ways in which elements of life and work impinged or supported his ability to perform the science to the highest standards possible. This concise analysis of the research into terrestrial magnetism at sea, at the Winter Quarters ice station and on sledging journeys provides the basis for commentary that follows on the indicators of scientific success and the factors that drove the outcomes for the expedition.

# Chapter 7: Success indicators and the drivers of scientific success

## 7.1 Indicators of scientific success

A truly successful hypothetical expedition might achieve all scientific objectives, return on time and within budget, receive public acclaim and provide a basis on which to secure financial support for another similar enterprise. The scientific staff might have new career opportunities opened to them on the back of new theories or phenomena discovered, new species identified or notable collections repatriated. The scientific publications might become the foundation for subsequent development of new theory and there might be commercial opportunities arising from discovery of new resources. Scientific collaborations, especially international collaborations in a context of national rivalry are another hallmark of success if they produce outputs. This first section of this chapter discusses the match between indicators of scientific success (identified in section 2.7, p. 60) and the outputs and outcomes of the *Discovery* expedition in relation to research into terrestrial magnetism in particular. Analysis of the significance of the contribution of each of the drivers of scientific success (identified in section 2.7, p. 61) forms the second key element of this chapter. The achievements and shortcomings of the scientific program are reviewed to inform conclusions about the significance of the research program of the *Discovery*, how outcomes might have been different and the significance of the expedition's legacies.

### 7.1.1 Objectives achieved?

Bernacchi wrote to his parents from Antarctica early in 1903 including a list of achievements of the expedition to date:

> Now with regards to the results of our expedition I had better give you them in order.
> (1) The discovery of extensive land at the east extreme of the Great Ice Barrier

(2) The discovery that McMurdo “Bay” is not a “bay” but a strait and that Mts. Erebus and Terror form part of a comparatively small island.

(3) The discovery of good winter quarters in a high latitude 77° 51' south with land close by suitable for the erection of the magnetic observatories etc.

(4) An immense amount of scientific work over twelve months in winter quarters principally physical and biological.

(7)[3] Numerable (sic) and extensive sledge journeys in the spring and summer covering a good many thousand miles, of which the principal is Capt. Scott’s journey upon which a latitude of 82° 17' south was attained and an immense tract of new land discovered and charted as far as 83° 30' south with peaks and ranges of mountains as high as 14,000 ft.

(8) The great continental inland ice reached…at a considerable distance from the coast and at an altitude of 9,000 ft.

(9) A considerable amount of magnetic work at sea, also soundings, deep sea dredging etc.

These are just the large principal results, there are many other minor ones.

(Bernacchi, 1903b)

The official instructions to the director of the civilian scientific staff did not clearly state any of the real objectives of the scientific work, but they did say that if any findings new to science were detected then all effort should be made to communicate this to the Joint Committee. Otherwise they are a statement of limitations placed on any materials generated by the expedition including diaries, journals and photographs. The scientific objectives of the expedition related to magnetic research were more clearly stated in the instructions to the commander of the expedition. They are paraphrased below, with commentary on the extent to which each was achieved (British National Antarctic Expedition, 1901).

- <u>Instruction:</u> The objects of the expedition are, … (b) to make a magnetic survey in the southern regions to the south of the 40th parallel and to carry on meteorological, oceanographic, geological, biological and physical investigations and researches.

[3] The numbering here is inconsistent as Bernacchi confused page numbers with paragraph numbers in the original document.

Outcome: The geographical exploration elements of this objective were achieved. The magnetic research was only partially successful.

- Instruction: The scientific work of the Executive Officers of the ship will be under your immediate control, and will include magnetic and meteorological observations, astronomical observations, surveying and charting, and sounding operations.
  Outcome: The officers of the ship contributed to the scientific effort and in Armitage's case, he probably applied significantly more time and effort to the magnetic work than the apparatus warranted.

- Instruction: You should endeavour to carry out the magnetic survey from the Cape to your primary base station south of the 40th parallel, and from the same station across the Pacific to the meridian of Greenwich. It is also desired that you should observe along the tracks of Ross, in order to ascertain the magnetic changes that have taken place in the interval between the two voyages.
  Outcome: Continuous records were made at Winter Quarters but there was no conscious effort to follow the tracks of Ross except within the Ross Sea. Observations made at sea in high southern latitudes were of no value although undertaken with regularity and diligence. Data was unreliable and never reported.

- Instruction: The expedition will be supplied with a complete set of magnetic instruments for observing at sea and ashore. Instructions for their use have been drawn up by Captain Creak and yourself and three of your officers have gone through the course of instruction at Deptford with Captain Creak and at Kew Observatory.
  Outcome: The Lloyd-Creak dip circle was found to be inadequate for the operating conditions. The *Antarctic Manual* instructions and the course of instruction for officers were insufficient to give Bernacchi any confidence that an understudy could take over his role in case of misadventure or movement away from the observatory at Winter Quarters.

- Instruction: As regards magnetic work and meteorological observations generally, you will follow the programme arranged between the German and British Committees, with the terms of which you are acquainted.

Outcome: The instructions in the *Antarctic Manual* contained an error and, as Bernacchi lacked familiarity with the regime of magnetic observations he was oblivious to his faulty timing. By virtue of continuous run Eschenhagen magnetometers, the data collection was sufficiently successful to provide global data sets that overlapped temporally. Nominal data pooling resulted between the German and British expeditions.

The objectives of locating the magnetic pole and building a long run set of observations at a high latitude was achieved. Aside from amassing additional data, no tangible progress towards solving the riddle of terrestrial magnetism was evident. It was unrealistic to expect any significant leaps in knowledge as the system of observations and the results collected were similar to those that had been in operation for decades. A lay person's view was that data confirmed known cycles of magnetic activity, provided detailed descriptions of the phenomenon of magnetic storms and gave a better understanding of the rate and direction of movement of the magnetic pole. In summary, some of the scientific objectives were satisfied and a number fell short but the instructions were indistinct and open-ended in most cases, just giving a general guidance, rather than an achievable target.

### 7.1.2 On budget?

In spite of a lavish provision compared to other expeditions of the era, the *Discovery* ran over budget by a significant amount. The whole expedition budget was committed before the ship departed from Britain. Markham had excelled at acquiring expedition funding, but he also expended that sum in an interesting manner. In hindsight, his insistence on construction of a new expedition ship and disregard of opportunities to purchase and refit an adequate ship was a folly. He knew of the need for a second ship to be sent as a relief expedition and he withheld this requirement from the organisers and funding sources. Only after *Discovery* was at sea did he commence the search to find and purchase the *Morning* (Yelverton, 2000, p. 67).

Freezing *Discovery* in the ice for an extra season caused the costs to balloon, creating a major embarrassment and precipitating the expedition to fall into disrepute in some circles. The Admiralty, as an instrument of the government, bailed out the expedition at great cost by purchasing, refitting and sending out the *Terra Nova* as well as the *Morning* in the summer of 1903-04. Scott was quoted in the New Zealand papers as having stated that the two-ship relief expedition was a waste of public money, but he moved quickly to recover from the potentially career limiting *faux pas.* The cost of overstaying was great, in the region of £15,000 an amount similar to Markham's unrealised expectation of the sale price of the *Discovery* (Huggins, 1903; Yelverton, 2000, p. 323).

### 7.1.3 On time?

The *Discovery* overstayed its planned campaign by at least twelve months. This was unsurprising as the likelihood of misadventure was well known for frontier expeditions to polar regions of the era. The cause of the extended stay relates to Scott's decision to overwinter the ship, then the impossibility of extricating the *Discovery* from the ice in the summer of 1902-03. Although the data and specimen collection phase overran the planned schedule, the publication of scientific reports was acquitted in reasonable time when compared to similar expeditions. To provide perspective, all of the *Discovery* scientific reports were published by 1912 whereas Drygalski's *Gauss* reports were still being released as late as 1931, partly due to the intervention of the First World War (Rosove, 2001, pp. 108-122). Mawson's *Aurora* (1911-1914) magnetic reports were only published in 1925. Shackleton's *Nimrod* magnetic report was never published, except as a narrative account of the trek towards the magnetic pole written by David (Shackleton, 1932, pp. 260-311) and later as a segment in the magnetic report of Mawson's AAE, where some of the data appeared for the first time (Mawson, 1925, pp. 50-52). Shackleton died in 1922 during the

*Quest* expedition and Mawson probably realised this was the last opportunity for publication of the data.

Extra value was gained scientifically by overwintering the *Discovery*, with an additional year's data obtained in magnetic and meteorological studies at Winter Quarters. The opportunities for additional sledge journeys also added significantly to the scientific value of the second year. Scott's western plateau journey gave magnetic declination values on an extended track away from the base. His party crossed the line of 180° declination, an important way point in the construction of the chart of declination in the region of the magnetic pole, but the accuracy of his longitude determinations is questionable. Bernacchi and Royds' barrier journey was especially valuable to the magnetic, meteorological and glaciological studies. Geographically it supported the idea that the ice barrier was extensive, mostly featureless and afloat. The second year gave Ferrar opportunity to geologise around the mountains in virgin territory, after breaking away from the role of support party for Scott's (November 1903) western polar plateau trek: "Captain Scott therefore arranged that I should accompany him to the edge of the inland ice, and should do as much geological work as possible on the return journey" (Ferrar, 1905). He discovered the Beacon sandstone complex that confirmed the continental nature of Antarctica, determined initially by David after analysis of Borchgrevink's Cape Adare samples from Bull's 1895 whaling campaign (David Branagan, personal communication, 7 October 2009). In summary, although the *Discovery's* Antarctic campaign ran considerably over time, some of the most significant outcomes were only achieved as a result of the additional opportunities provided by the second season.

### 7.1.4 Repeat funding?

Scott's second Antarctic expedition, the *Terra Nova* (1910-1913) was marked by an arduous pre-expedition drive for funding. Markham had managed all the fundraising effort for the *Discovery* expedition, but the *Terra Nova* was Scott's expedition. It was sanctioned, but not managed by the RGS and Scott struggled to get government, institutional and philanthropic support. Scott was aware of the importance of a robust scientific program to attract funding even though it was no secret that the prime objective of the expedition was to reach the geographic South Pole. The funding he received from the RGS and RS was parsimonious (£500 from the RGS) compared to Markham's earlier efforts and the level of support from the Navy was diminished on the second effort. He resorted to appeals to the general public and the outcome was a significantly smaller pot of funds with which to mount the campaign. Scott wished to have the *Discovery* again but it had been sold off to the Hudson Bay Company for £10,000, less than a quarter of its construction cost and was therefore unavailable (Savours, 2001, p. 74). The *Terra Nova* had returned to whaling after taking part in the relief expedition of 1904 and Scott was able to purchase her for £12,500 (Ryan, 2011, p. 216).

A handful of factors made funding harder to acquire. There may have been fatigue after the prior requests for Antarctic expedition funding coupled with a desire by institutions to redirect funds towards other explorations. The RS did not see itself as a vehicle to mount expeditions, but more as a facilitator for promulgation of outputs and outcomes. Executive members of the RS were aware of the difficulties of the relationship with the RGS during their joint management of the *Discovery* expedition at which time, even though they had provided funding and support, they had become powerless in the battle against Markham to keep the agenda focused on scientific outcomes. Scott was trying to raise funds on the back of a scientifically credible expedition program intended to provide balance to the objectives.

At the same time he was in deep conflict with William Napier Shaw (1854-1945) of the RS, over what he perceived as errors in the first meteorological report. Prospective fund providers probably saw Scott's *Terra Nova* as a high-risk venture with low prospects of bringing new scientific knowledge to light.

Although Bernacchi turned to tropical exploration after the *Discovery* expedition he retained a strong emotional connection to the Antarctic. He planned to lead an expedition for 1925 but it never eventuated. His plan was to establish a base in King George VII Land, at Biscoe Bay and have traverse parties, using Citröen Kegresse half-track vehicles similar to those used by Louis Audouin-Dubreuil (1887-1960) in 1922 to make the first crossing of the Sahara. Bernacchi negotiated for the purchase of the *Terra Nova*, and had the refit and delivery from Newfoundland scheduled to allow landing a party in early 1925. A feasible scheme of depot laying and support parties to allow two main treks to be undertaken for exploration of the unknown quadrants towards Charcot and Graham's Land, and south-east towards the Queen Maud Range and Weddell Sea region were planned. It was a sound plan with a program of scientific work to complement the exploration. Bernacchi's complete budget and staffing arrangements were detailed, but funding was not forthcoming and the expedition never proceeded (Bernacchi, 1924). Bernacchi had provided the initial finance in the planning stages then approached the government for the bulk of financial support, but got none. Bernacchi's failure to gain repeat funding in this instance is not a truly relevant indicator of scientific success, as Bernacchi was ageing and his plan, being highly ambitious, was therefore costly.

### 7.1.5 Promotion, peer recognition and career advancement

Scott's motivation for joining Markham's campaign was the prospect of promotion. He achieved that aim rapidly, being promoted from Lieutenant to Commander upon his transfer from sea service to the expedition in June 1900, then he was promoted further, to Captain, after the return of the expedition. These were not necessarily in recognition of Scott's service to science, but more likely in recognition of his successful exploration. His scientific contribution was recognised by Cambridge University barely six months after the expedition's completion and well before any of the data had been analysed: "Dear Captain Scott, I [Vice Chancellor of Cambridge] am commissioned by the Council of the Senate of this University to invite you to accept the <u>Honorary</u> Degree of <u>Doctor in Science</u>" (Beck, 1905).

Bernacchi did not pursue a career in science after his affairs in relation to the *Discovery* were wrapped up. A diary that has recently come to light in a private family collection explains the springboard to a new life. It commences:

> March 14th 1906, Set out with my wife on a journey to Peru the object of the journey to examine the primeval rubber forests in the interior …on behalf of Sir George Newnes who contemplates purchasing a large property of some 85,000 acres.
>
> (Bernacchi, 1906)

Bernacchi developed a sense for the rubber planting business during that first trip to the Amazon basin. His tour to the "Excelsior" plantation was to sparsely populated and extremely inaccessible regions and culminated in travel to the Inambari River in the upper Amazon Basin. By 1911 he was director of several rubber plantations (Skelton, 1911) and he maintained interests in rubber plantations throughout his life, making frequent trips to Malaya and other overseas destinations in pursuit of business opportunities.

Scientifically, Bernacchi peaked early then tapered off. He never returned to Antarctica after the *Discovery* but he did maintain a close, active interest in polar affairs and was well known in society in London as a result of his Antarctic exploits. He provided frequent, expert commentary on polar matters for the press and he maintained contact and correspondence with a number of his shipmates. Scott was best man at his wedding to Winifred Harris on 10 February 1906. A family anecdote tells how at his wedding, Scott giving his speech as best man, offered Bernacchi a place on any further polar expedition. His new bride, a formidable woman, told the congregation that Bernacchi would certainly *not* be taking part in further polar campaigns (Atkin, 2011).

He had been a fellow of the RGS since the *Southern Cross* expedition and was a Council member from 1928 to 1932. He was also a member of the British Association for the Advancement of Sciences and a foundation member of the Antarctic Club, established on 17 January 1929 the anniversary of the day that Scott and his party attained the South Pole. In 1935 he gave the Alexander Pegler lecture, entitled "Antarctic Exploration Past and Present" to the British Science Guild in London, of which he was also a member.

The recognition of greatest importance to Bernacchi was fellowship of the RS. He was nominated for membership by (George) Murray: "I forgot to say I put your certificate up for the Royal, signed by men like Kelvin, Rucker, Creak, Ayrton etc. I shall use all the influence I have, but you must not expect much at once" (Murray, 1905). He was never accepted as a fellow but he did stay in the public eye, for example as the "Organizing Director" of the successful Polar Exhibition of 1930 for which he gave the opening lecture. The exhibition was open for viewing from 2 to 15 July 1930 in the Central Hall, Westminster. Bernacchi called in favours from friends and colleagues and collected together an unprecedented and never repeated collection of valuable polar memorabilia including Scott's and Wilson's last diaries, numerous sledging pennants and equipment, charts and historical documents, portraits of explorers and paintings of polar scenes, models, flags, medals from private and public collections. Shackleton's famous lifeboat, the *James Caird* was also featured. Bernacchi complained that he had insufficient space to display all the materials gathered and he wrote to Mill in July and August 1930 noting the success of the exhibition. Overall 6,500 visitors came to the exhibit, 3,500 to see the new edition of Ponting's film of Scott's *Terra Nova* expedition and some profit came from sales in the bookshop. He edited the companion volume, the *Polar Book* and contributed to its content (Bernacchi, 1930b). It described the state of polar science of the time in each of the key disciplines and had contributions from well-known Antarctic scientists including Debenham, James Wordie (1882-1962), Mill, Simpson, Charles Wright (1887-1975) and Robert Rudmose-Brown (1879-1957). The profit from the book was £100 from the 3000 copies printed and the exhibition's total profits were around £300 (Bernacchi, 1930a). Bernacchi's reputation had been built upon his success as an Antarctic pioneer scientist and the successes of the *Discovery* expedition that provided professional credibility to his later enterprises.

### 7.1.6 Critical reviews and public perceptions

The scientific results of the *Discovery* expedition were first reported for public consumption during a lecture by Scott to the RGS. The elements of the speech were categorised as pack ice, icebergs, inland ice, glaciers, the Great Barrier and climate. Magnetic studies are not mentioned although they might have been found in the segment where "Captain Scott briefly referred to the results obtained by the expedition in some other departments" (National Antarctic Expedition, 1905). This lecture was reported in full in *Geographical Journal*, and is a report, rather than a review. Although the title implies the geographical results are the focus of the lecture there are some references to the scientific work. The first public acknowledgement of an error in the synchronous observations is found here, but the deficiencies in the magnetic force observations remained hidden. Scott stated the following:

> I am glad to have been informed that an unfortunate error with regard to the hours named for term day magnetic observations is not of such importance as was at first imagined, and, of course, the curves taken under normal conditions are of unimpaired value. It must be long before the full magnetic results are known, but Captain Chetwynd has already found that the observations for "variation" taken at sea and on sledge journeys work in remarkably well.
>
> (Scott, 1905a)

The *Physical Observations* volume was reviewed by an anonymous reviewer in the *Times Literary Supplement* under the heading of *Antarctic Earthquakes*. It considered the seismic studies to be unexpectedly valuable as some similarities between seismic shock waves and the transmission of telegraph signals might have led to new experiments on long distance communication technologies. The determination of the location of the magnetic pole was the only outcome of the magnetic surveys that attracted comment. The reviewer quotes Chree's remarks in the report that the magnetic and meteorological observers "set out on this important expedition with little or no preliminary training" and that they accomplished their "difficult task with remarkable skill and patience" (Antarctic Earthquakes, 1908). This is directed at the efforts of Bernacchi who was the central figure in all of the disciplines reported in the *Physical Observations* except the tidal studies. The review winds up with a critical reference to Bernacchi's late recruitment and the work of "those responsible for the expedition." The review does little to convey whether there is significance in any of the results, aside from the seismology, and gives a lacklustre view of the outcomes. Scott's final word to Bernacchi on the matter was that "This wretched Times reviewer is really very troublesome" (Scott, 1908c). Chree wrote a robust rebuttal, also published in the *Times Literary Supplement* that accused the reviewer of unreasonably selecting and interpreting quotes in order to throw a bad light on the organisation of the expedition. Chree praised the training and experience of Armitage and described Bernacchi "as the most experienced physicist available" (Chree, 1908a). The reviewer also stated that the organisers made a mistake of having an overly ambitious program of physical observations by the inclusion of atmospheric electricity, auroras, pendulum observations, seismology, tidal observations and terrestrial magnetism. This would have provided ample work for "at least two highly trained physicists."

Gregory reviewed the *Physical Observations* volume (Gregory, 1909b). His review was generally complimentary but wrote just one short paragraph on the magnetic results where he commented on the close agreement for the position of the magnetic pole between the separate methods of declination and inclination. A further review of the *Physical Observations* for the American Geographical Society's journal was published as a companion to a review of the second volume of meteorology reports. It commented that the long time required for preparation and publication meant "important facts and conclusions have long since found their way to the scientific public." It also described the work as "dry" and noted that the volume offers "little that is new" (Hobbs, 1915).

Scott had railed against reviewers after the release of the first meteorology volume writing to Bernacchi after reading the comments:

> I have been looking again at Shaw's remarks in the meteorological volume and my attention is called to a review in the *Times* [supplement] Aug 13th. It appears to me that Shaw has made a number of inaccurate & damaging statements and must be asked to explain them.
>
> (Scott, 1908b)

Scott states the review asserts that he (Bernacchi) failed to do the work of the man he relieved (William Shackleton), but this is clearly a misunderstanding on behalf of Shaw, as neither Shackleton nor Bernacchi had any significant involvement with the meteorological program. Scott believed this was an unnecessary and uninformed slur on the work of the scientific staff.

### 7.1.7 New knowledge and new directions of intellectual inquiry?

The *Discovery* magnetic science program was locked into a regime of data gathering and the roles of Armitage and Bernacchi were more akin to technicians than scientists. No significant theoretical breakthroughs regarding the phenomenon of terrestrial magnetism or its source resulted from the *Discovery's* magnetic research and no theories were disproved. More concise descriptions of diurnal, seasonal and secular change became possible and the *Magnetic Observations* report focuses on disturbances, or magnetic storms. An updated location for the region of the south magnetic pole was determined, but even this basic determination was of doubtful utility to later researchers in the field. The information allowed better estimation of the direction and speed of movement of the pole, determined to be trending towards the north-east since the prior estimate of Sabine from Ross's expedition (Chetwynd, 1908, p. 157). This was later discredited by comments in the magnetic report from Mawson's AAE stating the position was unreliable being based on observations taken on one side of the pole only (Webb, 1925, pp. 55-56). During his 1908-09 sledging journey to the magnetic pole during Shackleton's *Nimrod* expedition Mawson carried a pre-publication copy of the *Discovery* magnetic report (Shackleton, 1932, p. 307) to assist his estimation of the position of the pole rather than as a basis for scientific inquiry.

It was only through connections with the Arctic auroral work of Birkeland that any serious progress toward new directions in terrestrial magnetic theory, or the role of space weather progressed. Birkeland developed his theory about the channelling of charged particles ejected from the sun along geomagnetic field lines after work on his "Norwegian Aurora Polaris Expedition" of 1902-1903. He had previously conducted experiments to test his theories about the relationship between terrestrial magnetism and auroras by directing beams of cathode rays towards a magnetised terrella within a vacuum chamber (Jago, 2001, pp. 171-172). The science on the *Discovery* was characterised by data gathering only and experimental hypothesis testing of this sort was outside the realm of the magnetic program. Appendix B of the *Magnetic Observations* volume connects Birkeland's researches to those of the *Discovery* in a manner that is acknowledged as superficial, as the volume was almost ready for publication when his results became publicly available. Birkeland's report assembles data for magnetic disturbances between October 1902 and March 1903 and consolidates contributions from twenty five observing stations, mostly from the northern hemisphere. Birkeland's definitions of what constitutes a magnetically "normal" situation and what constitutes a "magnetic storm" vary from the standards for Kew and for the *Discovery's* data, so direct comparison and inference is not possible, although the synchrony of periods of magnetic disturbance across the globe are confirmed (Royal Society, 1909, pp. 246-274).

### 7.1.8 Research collections and new species

Analysis of studies in the full range of science disciplines during the expedition is outside the scope of this thesis, but some brief notes are in order to inform judgements about overall scientific success. The series of six volumes of natural history (one geology and five zoology and botany) were published between 1907 and 1912 by the BMNH. Rosove's bibliography details the separate sections of each and shows that numerous specialists analysed the collections and described the many new species (Rosove, 2001, pp. 345-347). Although the oceanographic work carried out was "limited" and the marine collections mostly represent the shallow waters of McMurdo Sound, the collections include "a fair share of species new to science" and are still considered to be of great significance and value for reference and research (Rainbow, 2005). A number of Type specimens (the actual examples used to describe the physical characteristics of new species) are preserved in the collection.

Gregory wrote two extended reviews of the scientific reports from the four expeditions to the Antarctic between 1901 and 1904. No new species of birds or seals were captured on the expedition according to his reviews, contrary to early reports of a new species of bird from South Trinidad Island, but the first known emperor penguin colony was detected at Cape Crozier in October 1902. For the general readership, the most easily engaged sections of the scientific reports are those written by Wilson on the seal and penguin biology. In the same volume, the museum zoologist William Pycraft (1868-1942) debunked Wilson's ideas regarding the status of the emperor as the most primitive form of penguin, and possibly of all birds. He argued: "the old view that the feathers of the penguins are allied to the scales of snakes and thus indicate the primitive nature of the penguin, is without foundation" (Gregory, 1908). This means that the winter journey by Wilson, Cherry-Garrard and Henry "Birdie" Bowers (1883-1912) to Cape Crozier to collect emperor penguin eggs in mid-winter of 1911 during Scott's *Terra Nova* expedition was probably an ill-informed folly, bent on progressing scientific research in a direction that Pycraft argued was a dead end.

Four new species of fish were collected, and five of the other six collected had previously been collected by the *Southern Cross* expedition. Numerous new species of invertebrates were collected including thirty molluscs, ten nudibrachs, eighteen amphipods, seven ostracods, two cirripedes, three new genera of *Pycnogonida* (as well as confirmation of the existence of a ten legged sea spider), eleven hydroids and eight sponges. Botany was less prolific with two new mosses being collected at Granite Harbour and some marine algae. All the specialist scientific staff noted "the smallness of the collections" and, in his introduction, Hodgson noted the limited opportunities for collection except at Winter Quarters. Gregory's review of the second tranche of reports was published just over a year later expanding the tally of new species for the *Discovery.* Amongst the insects, one new species of *Collembola* (springtail) is added as well as one additional mollusc. Nine previously unknown copepods were found and one new starfish, two species of sea-anemone and twenty new sponges falling into six new genera (Gregory, 1909a). The same review covers the outcomes of the meteorology and physical sciences. The total scientific output of the British, Scottish, German and Swedish expeditions that took part in the 1901-04 campaign in the Antarctic formed "a library of about thirty volumes" of which the *Discovery* contributed nine plus a separate album of photos and sketches (Gregory, 1908).

### 7.1.9 Detection of natural resources

No valuable new resources of significance were discovered. Ferrar discovered a thin seam of coal containing distinct leaf inpressions that indicated a previously temperate climate (Royds, 2001, p. 308). As the Antarctic continent is mostly covered by ice and snow it is less than ideal as a potential site for mining mineral resources. The potential value of the southern ocean fisheries did not figure in any of the reports or narratives of the expedition. Although seals were abundant they were not found in the dense populations found on sub-Antarctic Islands, most of which had been culled to the brink of extinction by orchestrated campaigns such as those operated on Macquarie Island by Joseph Hatch of Invercargill (1837-1928).

In spite of Armitage's letter to Keltie stressing the potential commercial value of the findings of the magnetic research, nothing of consequence for mariners came out of the expedition's findings (Armitage, 1901b). The economic value of pure scientific research is almost impossible to quantify so, although the winter station and sledge journey magnetic observations continued laying foundations towards terrestrial magnetic theory, they were of no economic value.

### 7.1.10 Successful collaborations?

The issue of synchronous term day and term hour observations is highly confused. There are two matters of concern. Firstly, the arrangements for synchronous observations were not carried out successfully. Secondly, the planned sharing of data never resulted in a pooled data set or analysis of a truly global regime of observations.

The agreement between the organising committees of Drygalski's *Gauss*, Markham's *Discovery* and numerous land based magnetic observatories was for set periods of synchronous magnetic observing over a twenty-four hour period, on the first and fifteenth of each month of 1902. In addition there were "term hours" during which manual observations were to be made every twenty seconds and those observers with drum recording magnetometers were to run them at the (sensitive) high speed for the hour. The agreed term hour commenced an hour later each subsequent term day. In this way any magnetic disturbances could be detected and their synchronicity or lag across the globe could be detected, and high resolution observations would eventually have been made during each of the twenty-four hours of the daily cycle.

Correspondence between the British and German committees and schedules of operations are in the RGS archive but as a number of them are undated and it is not always clear who the authors are, the situation will probably remain unclear. The correspondence during the preparation period specified the arrangements as early as November 1899. The minutes of the German "Sub-Committee of the Scientific Council for Meteorology and Terrestrial Magnetism" (translated by Mill) contain details of proposed arrangements for the benefit of the "Committee of the British Antarctic Expedition." They state that term hours should commence at: "12 noon (Greenwich) on 1st March 1902" (Sub-Committee of the [German] Scientific Council for Meteorology and Terrestrial Magnetism, 1899). Scott responded later to German proposals: "the program forwarded by you is accepted in its entirety for adoption by the British Expedition" (Scott, 1901a).

The undated (English) document entitled *Programme of Scheme of International Observations of Terrestrial Magnetism during the period of Antarctic research. 1902-1903* follows in this sequence of documents in the archive. It specifies all matters in relation to the observations with calculation methods and instrumental requirements. It contains a schedule for term day and term hour observations in an identical layout as published in the *Antarctic Manual,* but it varies from the German scheme. The first term day is listed as 1 *February* 1902 and observations are set to commence at *midnight* (British National Antarctic Expedition, n.d.b). Then follow appendices to that program, including a sample observing form that commences at *noon GMT* (British National Antarctic Expedition, n.d.c).

Bidlingmaier on *Gauss* was working to the timetable that commenced according to the German proposal:

> March 1st had been designated by agreements as an International Magnetic Day. Hourly readings were to be taken over 24 hours, and for one hour, which on this occasion ran from noon to 1.00 p.m. GMT, they were to be taken every 20 seconds.
>
> (Drygalski, 1989, p. 144).

The *Discovery's Magnetic Observations* report is at odds with these details:

> The term days all started at Greenwich midnight. On the first of the regular term days, February 1, 1902, the term hour was 0-1 a.m., G.M.T. On the second term day, February 15th, 1902, it was 1-2 a.m., G.M.T., and so on, advancing an hour each time for the 24 term days, up to and including January 15, 1903.
>
> (Royal Society, 1909, p, 146).

The *Antarctic Manual,* from which Bernacchi worked, gives yet another version. Starting at 1 February, the first term hour was to commence at midday GMT and run until 1 p.m. GMT. It also suggested, unrealistically given the ship's exploration schedule that instruments should be in place for testing on 1 January from 10 a.m. then 15 January from 11 a.m. The error is partially acknowledged in the *Magnetic Observations* volume where Chree says:

> …a mistake had somehow crept into the Antarctic 'Manual' which made each term hour 12 hours later than it should actually have been, and the observer, Mr Bernacchi-in the absence of any information to the contrary-naturally supposed the 'Manual' to be correct.
>
> (Royal Society, 1909, p. 201).

It appears that even this acknowledgement of the error contains further errors. Assuming Bernacchi was making his term hour observations according to the manual, he would have commenced at noon GMT, correctly, and in accord with Bidlingmaier, but he would have assumed that the first term hour would have started in 1 February, so his 1 March term hour was actually shifted out of synchrony with all other observing posts by only two hours, not twelve as reported by Chree. The comment that "The extended scheme proved impracticable in the Antarctic" is an understatement (Royal Society, 1909, p. 201). There is almost no consistency across the British documents containing schedules of observations. In the magnetic report for the *Terra Nova* expedition Chree referred to collaborative results from the *Discovery* expedition as a "fiasco" (Chree, 1921, p. 158). In addition to the failure of synchronised observations it was a period of nominal space weather activity, a solar minimum, so magnetic disturbances were weak and few.

It is possible that the best results for the cooperative scheme might have been gained from the *Discovery,* as it was the furthest south and closest to the magnetic pole. If Bernacchi had been recruited in a timely manner he most likely would have been more familiar with the protocols and it's unlikely that he would have been deceived by the incorrect *Antarctic Manual* schedule, his only source of information on this matter in the Antarctic. Also, if there had been consistent scientific leadership from early in the preparations, Bernacchi's mentor would have been alert to this error.

The outcomes are as confused as the arrangements for data gathering. The magnetic science reports of both the *Gauss* and *Discovery* failed to include results from each other in spite of the intentions to do so during planning. The German authorities suggested that the magnetic curves should all be "copied on squared paper and published in this form, so that anyone could read off the absolute value answering to any specified instant in time" (Royal Society, 1909, p. 202). However, Chree decided it would be better use of the publication opportunity to provide the tables of the fast run observations from Christchurch instead, as Farr and Skey had taken fast run observations over the full twenty-four hours of the term days, not just the specified term hours (Royal Society, 1909, p. 202). This is the only reference to results from *Gauss* and there is no explanation as to why the *Discovery* reports completely omit results from the German expedition.

Drygalski's choice not to include *Discovery* data was a conscious decision after he read the *Magnetic Observations* volume, published prior to the *Gauss* results. The German report explains the rationale for the omission. Chree sensed some of the McMurdo results were unreliable and suspected instrumental error as the cause, describing some results for rate of change of declination as "barely credible" (Royal Society, 1909, p. 81). Drygalski decided to test for instrumental errors in the German data by comparison of Bidlingmaier's *Gauss* ice station values against their Kerguelen base station observations. He found that they were in accord and could be considered reliable. The correlation coefficient between the monthly average of H (horizontal magnetic intensity, or force) at the Kerguelen station and the *Gauss* station reached the high value of + 0.0954 (compared to an assumed error only 0.020), a "brilliant" example of the accuracy of the measurement at both stations under these difficult circumstances. Drygalksi therefore agreed with Chree's analysis that the *Discovery* data was unreliable and rejected it (Drygalski, 1925, pp. 400-401).

In contrast, there was a successful collaboration in data sharing for the meteorological publications of the *Gauss* expedition. The following nations took part in the meteorological cooperation: Chile, Argentina, Capeland (South Africa), Australia and New Zealand. Secondly, German, British, Dutch and American ships handed in data. Thirdly, the publications drew on the material of the German, British, Swedish, Scottish and French Antarctic expeditions. Lastly, the material from the observatories on Kerguelen Island, Laurie-Island and Staten Island is included (Pascal Schillings, Personal Communication, 22 December 2012).

### 7.1.11 Natural phenomena, species and landmarks named for scientists

Scott quickly worked over the charts with Wilson, Mulock and Markham prior to meeting King Edward at Balmoral to ensure that features were named for sponsors and key members of the organising committees (Yelverton, 2000, p. 328). These were not in recognition of scientific achievements however. No new natural phenomena were discovered, although, by discovering that McMurdo Strait was not a bay, the question of currents taxed the minds of Hodgson and Barne who observed changes in the flow rate and direction of the water beneath the ice off Hut Point (Scott, 1903).

Various topographic features are named for Bernacchi, including Bernacchi Head on Franklin Island (76° 08' S, 168° 20' E) and Cape Bernacchi (77° 29' S, 163° 51' E) on the coast of Victoria Land (Australian Antarctic Data Centre, 2012) but these were named during the *Southern Cross* expedition and no new features were named during, or after the *Discovery* expedition to mark his contribution. Cape Armitage at Winter Quarters on Ross Island (77° 51' S, 166° 40' E) (Australian Antarctic Data Centre, 2012) was named for Armitage, probably in recognition of his overall contribution, not just his scientific work. In the zoology and botanical collections there are numerous genera and specific epithets carrying the names of Hodgson, Wilson and *Discovery* (Rainbow, 2005). On a clear day Mount Discovery dominates the skyline across the sea ice from New Zealand's Scott Base, on Ross Island, a visible reminder of the exploration and scientific heritage of the locality for modern scientists.

### 7.1.12 Technologies, equipment or procedures retained

There are some items of equipment that are familiar and iconic symbols of Antarctic exploration that have remained almost unchanged since 1904. These include marker flags on bamboo poles, pyramidal polar tents and timber sledges. These items of kit are basic to outdoor work and survival, and are ancillary to science. In the scientific arena, weather balloons and Stevenson screens (for protection of the meteorological instruments) are still in common use in polar and global meteorology. The magnetic instruments used on the *Discovery* and *Gauss*, or derivatives of them, continued in use for most of the expeditions of the era and beyond. Eschenhagen magnetometers, Kew pattern unifilar magnetometers, Barrow dips and Lloyd-Creak dip circles were used on Scott's *Terra Nova* (Chree, 1921, pp. 1-7, 410-430) and on Mawson's *Aurora* expeditions (Webb, 1925, pp. 18-24; Riffenburgh, 2011, p. 150). The *Terra Nova* used exactly the same Eschenhagen magnetometer as the *Discovery* (Chree, 1921, p. 18) and likewise with the Lloyd-Creak dip circles (Dover No. 143 and No. 149), and again the results for magnetic force went unpublished, although there is a more thorough treatment of declination and dip at sea in the report of this second expedition (Chetwynd, 1908, p. 133; Chree, 1921, pp. 429-449).

Mawson's *Aurora* expedition had "One Lloyd-Creak dip-circle, sea pattern, as modified by Dept. Ter. Magnetism, Carnegie Institution" (Webb, 1925, p. 18). One legacy provided by the *Discovery's* science and that of the *Gauss* was to guide the remanufacture of the Lloyd-Creak by the Carnegie Institution to improve its performance at sea and in icy conditions. Another legacy was the proof of the reliability and utility of Professor Eschenhagen's clockwork magnetograph mechanism. A mechanism similar to that was established at New Zealand's Scott Base magnetic observatory on Ross Island (77° 51' S, 166° 46' E), within a few kilometres of Hut Point (Australian Antarctic Data Centre, 2012), in 1957 during the International Geophysical Year (IGY). It was still in use as late as 1983 (Roper, 1983) and is shown at Image 11. The magnetometer shown above at Image 6 (p. 198) was in use at Watheroo in Western Australia for forty years between 1919 and 1959 and a similar magnetometer remained in use at Australia's "Mawson" Antarctic base at least until 1960 (Syd Kirkby, personal communication, 10 May 2012). Although auto-recording, networked apparatus is now in use at the Scott Base magnetic observatory, the constant recording apparatus must still be calibrated against manual absolute measurements.

Image 11: Drum magnetograph in the Antarctica New Zealand, Scott Base magnetic variation house (author's photo).

*Discovery* had been a proving ground for a range of technologies and techniques. Scott's *Terra Nova*, using similar, and in some cases the exact same magnetic instruments, set out to reproduce the observing regimes of the *Discovery* at their new winter base, Cape Evans, just a short distance north of the old Winter Querters base. This may have been as a means of reference or it may have been to cover the numerous deficiencies in the results obtained from the *Discovery*. The doubtful nature of these was characterised by Chetwynd's need to discard many absolute observations as unreliable (Chetwynd, 1908, p. 139) and Chree's decision to unconventionally adjust the base line readings for the absolute observations (Royal Society, 1909, p. 81).

## 7.2 The drivers of scientific success and *Discovery's* outcomes

The factors identified by the author during the initial stages of this research as prime drivers of scientific success on polar expeditions around the Edwardian era are reviewed in this section. Each driving factor is analysed here in consideration of the scientific success indicators discussed above for the scientific outputs and outcomes of the *Discovery*, with a special emphasis on the work of Bernacchi and the broader magnetic science program. This section draws together conclusions on the relative importance of the contribution of each driver to the expedition's outcomes.

### 7.2.1 Historic and cultural context

The *Discovery* expedition operated during a period of shifting intellectual tradition. Three key elements of the performance of science on nineteenth century navy expeditions were changing. Firstly, there was a shift away from the standard of officers as scientists and a trend towards appointment of paid civilian scientists. Secondly, the paradigm of scientific work in the field being carried out by observers or collectors who then repatriated their data and collections for analysis and publication by specialists in museums and universities was shifting. The Humboldtian process of empirical collecting was starting to be replaced by inquisitive, hypothesis-driven science and a new breed of experimenters and designers of research programs began replacing collectors (Bernard Stonehouse, personal communication, 19 August 2011). The third shift is the changing priority of exploration over science. The later *Nimrod, Terra Nova* and *Aurora* expeditions engaged more, better-qualified scientists than the *Discovery* and the intellectual atmosphere in the wardroom of these expeditions was most likely very different. Note also there were almost no glacial studies on the *Discovery* but on the *Terra Nova*, just seven years later, Wright, Priestley and Griffith Taylor had a robust program of studies in the discipline.

The *Discovery* represented a transition stage of the shift with a mix of officers and civilians practicing science. Royds, Armitage, Shackleton and Barne all assisted with some form of scientific observing or collecting, and there was almost an even balance between numbers of civilian scientific staff and officers engaged in scientific work. *Discovery's* research was carried out by scientists who were not yet eminent in their disciplines, rather than by the experienced, high calibre career scientists found on the expeditions whose leaders were scientists. The *Challenger* represented the commencement of the shift. It was a naval vessel but was notable for its appointment of a professor as scientific leader and the selection by the RS of a strong team of six civilian scientists (Jones & Jones, 1992, p. 216).

Civilian scientists staffed the most scientifically successful Antarctic expeditions prior to the Great War, and Hayes' review of scientific outcomes of British expeditions of the era concludes: "The scientific results of these expeditions have been proportionate to the number and ability of the scientists taken out" (Hayes, 1928, p. 259). Mawson's *Aurora* and Bruce's *Scotia* expeditions had almost exclusively civilian staff, although having no naval connections they were not tied to any intellectual tradition. Scott's *Terra Nova* did retain some naval connections, but the scientific crew were carefully selected civilians with experience and qualifications superior to those on *Discovery*. There are exceptions to the trend of diminishing involvement by officers in scientific roles in the RN. For example, Commander George Tabeart, RN, recently of the polar survey vessels HMS *Endurance* and HMS *Scott*, was called upon to make shore landings for the purpose of magnetic survey from time to time in the Arctic, so the tradition of officers as scientists is not completely dead (personal communication, 3 October 2011).

*Discovery* science was still modelled on the paradigm of gathering data and collections in the field then passing that material over to institutionalised specialists. Markham made arrangements for disposal of materials to the appropriate specialists as an afterthought. The civilian scientists on *Discovery* expressed their interest in remaining involved in the analysis and publication of their collections, and in the case of Bernacchi, Ferrar, Hodgson and Wilson they succeeded to varying extents.

Prior to the *Challenger*, the primary purpose of expeditions was geographical exploration. Science was incidental except in a handful of cases. The *Challenger* was purely a scientific enterprise that represents a turning point in focus. Most of the Antarctic expeditions between 1897 and 1914 had dual agendas of exploration and science, but of those, *Scotia, Gauss, Française, Pourquoi-pas?, Antarctic* and *Aurora* had stronger science than exploration programs. Markham's influence ensured *Discovery* was stronger in the exploration agenda.

In the magnetic science the collaborating observatories whose data was finally used in the scientific reports were mostly vestiges of the old Imperial network, and almost exclusively from the northern hemisphere, so the collaborations did not provide the sought-after global coverage. It remains unclear how the Pola observatory in Austria came to be involved, but aside from it, the observatories were remnants from the British Empire.

The full cycle of scientific method from theory, preparation, experimental design, gathering, analysis, review of the theory, and finally publication, is not evident in the program of *Discovery* but it was not completely out of step with other Antarctic expeditions of the era. The stand out scientific expeditions of Drygalski, Mawson, and Bruce followed a similar paradigm of collecting although their programs were organised in a more strategic manner and performed by more scholarly and experienced scientific staff, and under scientific leaders that were experienced in field research in extreme conditions.

Mawson broke the metropolitan/colonial nexus with his expedition that, although partly reliant on institutional support from Britain, was essentially staffed by Australians and New Zealanders, and operated as an independent expedition. The data reduction and the majority of the published material was prepared by the chief magnetician to the expedition, Webb (1925, pp. 1-200) while Chree provided the expert commentary on the results (1925, pp. 201-285) as he did to numerous other expeditions of the era including *Discovery*, *Scotia* and *Terra Nova*.

The historic context provided models around which Markham developed the *Discovery* expedition. His motivation was to re-establish British pre-eminence as a nation of explorers, a nation that could still expand its empire and a nation whose Navy was supreme. These ambitions were partially achieved, but it took Admiral Fisher's reforms and the introduction of dreadnoughts to re-assert the position of the RN in the global context. Exploration on the expedition was successful with the new furthest south record of 82° 16' S (Scott, 1905b, Volume 2, p. 79) and numerous other sledge journeys that penetrated the interior as none had done before. The Ross Sea quadrant became a territorial claim that eventually passed on to New Zealand. The *Discovery*, in spite of its shortcomings as a scientific research vessel on this voyage remains an iconic representation of British maritime power in spite of its private, rather than naval registration.

The paradigm of data collection remained dominant throughout the operations of the *Discovery's* scientific program, and dominated expedition science for at least fifty years, until the IGY. Pressing ship's officers into service for scientific observing was an element of the tradition that did not serve *Discovery* well. Armitage was a competent observer but not a trained physicist, so one can speculate how different the outcomes of observations at sea might have been if Bernacchi had embarked with the *Discovery* at the outset of the expedition? Bidlingmaier, with the advantage of sea time on the *Gauss,* was able to develop observing protocols for the Lloyd-Creak dip circle that provided useful data, and it's reasonable to speculate that Bernacchi could have done similar work. The working conditions were comparable as the *Gauss* also rolled a great deal and the instruments were identical. Most of Armitage's magnetic work at sea was dismissed as worthless, and some of the observations made at the rifle range observatory on Red Hill behind Simon's Town were also rejected (Creak, 1901c). These facts do not support Markham's belief that officers could turn their hand to anything, as long as the fact that Armitage was from the merchant service, not the RN, is disregarded.

The tradition of dispersing collections and data collected in the field (the periphery) to specialists in museums, universities and military institutions (the metropolis) was shifting around the time of the 1901-04 campaign. There was some involvement by the civilian scientists in data reduction, analysis and preparation for publication of the material from the *Discovery*. Bernacchi, Hodgson and Ferrar all contributed to the reports in their own disciplines. Meteorology was completely taken out of the hands of Royds and other observers.

### 7.2.2 Patronage, funding and institutional support

The *Discovery* was a well-funded enterprise and Markham's need to source additional funding for relief expeditions is a reflection on the distribution of funds, rather than inadequacy of the total. No contingency was set aside for the relief expedition that Markham knew was necessary, even before departure of the *Discovery*. Although the scientist's wages were paid out of general funds, there were few other expenses directly related to the research. Construction of the ship's magnetic laboratory, the dredging and sounding apparatus and associated deckhouse laboratories were costs absorbed into the ship construction bill. Instruments and equipment were on loan from the Admiralty, the RGS and the National Physical Laboratory. Costs related to shipping and certification of instruments were nominal in the scheme of things. There was no financial allowance for the post-expedition work of reducing and analysing data and collections or publication of the scientific reports. Most of this work was achieved through the goodwill of the Admiralty, the National Physical Laboratory, the RS, the BMNH and especially individual efforts by its staff in their own time (Lankester, 1905). In hindsight, the expense of construction of a new expedition ship could have been avoided. The vessel's capability as a floating magnetic laboratory was under utilised and the same was true for the sounding, dredging and trawling capability of the ship.

Was the funding sufficient to achieve the best scientific outcomes? Yes, initially, but funds that should have gone to post-expedition analysis and publication were not quarantined. Did the sponsors get (scientific) value for money for their investment in the expedition? The answer here is no, as the predicted commercial benefits went unrealised. The body of data on terrestrial magnetism was expanded but the impossibility of placing a monetary value on research programs that add to the body of knowledge without generating measureable commercial outcomes is self-evident.

The paradigm of abundant public funding for explorations shifted after the *Discovery* expedition. The notable expeditions that followed relied most heavily on philanthropy and public subscription for finance. British governments, the RGS and the RS were more reserved in their support of expeditions like Shackleton's *Nimrod* and *Endurance*, Scott's *Terra Nova* and Mawson's *Aurora.* Markham's failure to bring the expedition home within budget and mishandling of the two relief expeditions were a disservice to all expedition promoters that followed.

Patronage and funding went hand in hand, as funding was rarely forthcoming if there was no support or patronage by key institutions or senior figures. Both are highly important, but for funding there is a minimum threshold that must be exceeded to allow an expedition to proceed. In the case of the *Discovery* the funding and patronage was a feedback system. The first funding boost from Longstaff assured the prospects of the expedition prompting further donations. Sponsorship by the RS and a certain amount of momentum in fundraising made royal patronage possible, which in turn promoted further funding and agreement of the RN to become involved. Intellectual patronage of the expedition by the RS failed to reach potential. After the two societies fell out there was no effective direction to the magnetic program from the RS, in spite of the abundance of physicists amongst its fellows.

There was no direct relationship between levels of funding and scientific outcomes of expeditions of the Edwardian era. Borchgrevink's *Southern Cross* was well funded for a single ship expedition with a very small crew, but the scientific outputs were modest. Bruce's *Scotia* and Drygalski's *Gauss* were modestly funded (see Table 2, page 121) but the scientific outputs were exceptional. Abundant funding is not a critical driver of success although for each expedition there is a threshold value that must be reached for the operation to proceed. Funding is one of the "make or break" factors.

### 7.2.3 Leadership and governance

The successful model of modern scientific research involves senior practitioners designing the research regime, procuring funding, designing the experiments or observations, then recruiting and directing the activities of technicians that operationalise the plan. Care to foster data management and analysis leading to publication is a characteristic of modern science and the model was also appropriate in 1901.

There was no effective governance structure overseeing the *Discovery* expedition preparations and, once at sea, control on board was maintained by the fiction of the RN hierarchy. In spite of a Joint Committee comprised of thirty-two eminent representatives of the RS and RGS it was Markham who, for better or worse, maintained ultimate control of expedition preparations. His efforts to get the expedition up are praiseworthy and there was no other motivator with the tenacity to have made it become a reality but the evidence shows that Markham may not have been as familiar with the science as might be expected of a person with almost absolute control of the expedition preparations. Few people dared challenge Markham on any matter and George Murray described his manner in meetings thus: "Upon my word Markham is a man. Foster and the others were mere invertebrates" (Murray, 1901d).

Scientific sub-committees were generally ineffective. The minute book shows that the magnetic sub-committee met only twice. The first meeting in mid 1899 provided general guidance about which magnetic research could and should be undertaken, what instruments might be suitable and special considerations for the magnetic observatory during construction of the ship. The second meeting in February 1900 resolved that there should be a civilian trained observer, but no names were put forward and ultimately there was no evidence of committee involvement in the recruitment of the physicist (British National Antarctic Expedition, 1899).

A question often posed about the expedition is to what extent would scientific outcomes have been different if Gregory had joined as scientific director? Specifically, would he have been able to effectively lead the scientific work of the officers as well as the civilians, or would Scott's direct and absolute command have trumped him? Day-to-day logistical decisions at sea and on the ice, balancing the tension between exploration and science, would have required delicate negotiation between Scott and Gregory, and Scott's absolute control would have favoured Markham's preference for exploration. The scientific outcomes would have been superior under Gregory due to better planning and organisation at the outset, better recruitment, better comprehension of the scientific and logistic requirements then better coordination of analysis and publication. On the *Discovery* Scott proved to be sympathetic to the scientific operations, but only when they did not clash with the needs of exploration. After publication of the first meteorology report, Field criticised Scott's scientific acumen:

> Captain Scott is evidently unable to realise the standard of the work which was expected of his staff and has no right to complain when its shortcomings are pointed out. To pass them over in silence might lead to their repetition in future expeditions. (Field, 1908)

Evidence shows that the expeditions of the era with scientists as leaders were more productive scientifically (Rosove, 2001. pp. 49-54, 59-72, 104-123 & 253-260). One exception was the *Terra Nova*, but the abundance of scientific output was boosted by the availability of abundant funding from the public subscription for Scott's family after his death. Drygalski's believed in the same model of leadership as Gregory, that the leader should have ultimate authority in all arrangements and decisions, and that the commander should be responsible for the operation of the ship only (Drygalski, 1989, p. 11). A developing trend toward scientists as leaders is confirmed by the example of ANARE expeditions of 1947-48 to Heard and Macquarie Islands: "The leader on each island was a scientist in the tradition of scientific leadership established by Sir Douglas Mawson" (Fanning 1981, p. 36).

In *Discovery's* case the scientific outcomes were affected significantly by leadership and governance decisions, especially at the preparation stage of the expedition. Ineffective governance translated directly to ineffective preparations and although good governance can't guarantee success, poor governance most likely leads to failure. Decisions about the objectives, the logistics and the balance of control between the (mostly non-existent) scientific director and the commander changed the course of the work of the expedition from the outset. In spite of Scott's benevolent approach to the scientific programs, there was a notable scientific leadership vacuum after Mill left the ship at Madeira. The work program of the physicist at the ice station was ambitious and the magnetic reports contain many instances where, either observer errors or instrumental errors caused data to be considered unreliable and was excluded from results. Leadership and governance is the single most significant driver of scientific success. It influences most of the other drivers. Poor leadership and organisation can be fatal to an expedition, as was the case in Borchgrevink's *Southern Cross* and Filchner's *Deutschland*.

### 7.2.4 Preparations

The haphazard nature of the expedition preparations has been described in section 5.1. The *Discovery's* governing committees were either dysfunctional or ineffective, or both, and the conflict within the Joint Committee prevented effective operation. Markham's influence prevailed in almost every instance and the ongoing disputes over the objectives and expectations, scientific leadership and logistics left the scientific program subservient to exploration. The magnetic sub-committee was benign, providing no useful contribution to planning or preparation. After Scott's trip to the continent to meet Nansen and Drygalski in October 1900 he knew that, in spite of the long gestation of the expedition, the *Discovery* preparations were running critically behind. The knock-on effects were late recruitments, late arrival of instruments and equipment, inadequate training and a diminished opportunity for sea trials with the scientific apparatus.

Once established at the winter station there were preparations for Antarctic fieldwork that could have been made, but were neglected. Practice at erecting tents, using the cookers, skiing, dog and man-hauling sledges could have been acquitted during the winter months when there was less opportunity for active field work and outdoor science. There was an abundance of idle time for the lower deck and failure to prepare well for travel away from base and outdoor survival showed naïve optimism. Skelton wrote to Scott in 1912 about ski training after a trip to Switzerland: "It is such a pity we had no one on the Discovery to teach us properly, because everything depends on the first lessons" (Skelton, 1912).

Diligent preparations are not a guarantee of success but poor preparations can directly diminish scientific outputs. On *Discovery* the diligence of individuals compensated for haphazard and late running preparations. Poor preparation had a significant affect on the final outcomes.

### 7.2.5 Instructions

The instructions to the commander were explicit regarding the sector of Antarctica to be explored and the timing of, at least, the initial ship movements. Scott, as commander was locked into the program dictated by these instructions. The instructions to the scientific director were much less explicit and failed to give direction regarding expected outcomes and the means by which they might be achieved. The responsibilities of the position were never stated. If it was a case of giving an open hand to follow lines of inquiry according to emerging information, then only a scientific practitioner such as Gregory, Bruce or Mawson would have had the intellectual agility to take proper advantage of opportunities. These are moot points in the circumstance where Scott took on both roles. The *Antarctic Manual* was an additional source of instruction to the scientific work of the expedition, especially in relation to seawater analysis and meteorology but the terrestrial magnetism instructions were brief and, as shown above, were faulty in a way that caused incorrect data collection.

In most circumstances correct, explicit and well-informed instructions are essential to the work of a scientific research program, especially where the practitioners do not have a strong ownership of the work or the outcomes and synchronised observing is planned. The exceptions are where scientists are highly motivated and have the agility to take advantage of opportunities presented to them, such as Murray Levick’s (1876-1956) adelie penguin life history and behaviour studies performed at Cape Adare during the *Terra Nova* expedition (Hooper, 2010, pp 151-152). The officer in charge of the meteorological observations, Royds, was diligent but disengaged from the work, becoming bored and frustrated by the routine, especially in winter (Royds, 2001, p. 151). He had some training but on the expedition’s return he had no involvement with the outcomes. Fortunately there were lengthy detailed instructions for meteorology observing in the *Antarctic Manual*. The magnetic observer Bernacchi was also somewhat disengaged, but not through a lack of interest or as a result of conflicting priorities related to management of the ship. He was appointed late, so took no part in the first six months of the magnetic work at sea. Instructions were critical to his successful performance of the work in Antarctica as he had little opportunity to become familiar with the expectations and procedures required by those that set the magnetic science agenda. He had no part in the development of the scientific program and acted as an observer only until he commenced to make some post-expedition contribution to the results analysis. The importance of scientific instructions ranks highly amongst the drivers of scientific success in late Victorian expeditions, especially within a leadership vacuum.

### 7.2.6 Collaborative relationships

Collaborative scientific relationships can be effective strategies to enhance the eventual value of individual efforts. In scientific programs they fall into two categories: firstly program development and coordinated observations and secondly, joint data pooling and publication. Global phenomena such as terrestrial magnetism, meteorology, tides, gravity and seismology are candidates for networked observations. The same is true for extra-terrestrial phenomena like auroras and space weather, although these areas of study were in their infancy in 1901.

In the case of the *Discovery* the prospects for collaboration were exceedingly good as there was agreement at the outset of synchronous magnetic observing between the *Gauss*, the *Discovery* and numerous land stations. These were listed by Markham as Kew, Falmouth, Bombay, Mauritius, Melbourne, Christchurch, Staten Island, Kerguelen, English Expedition, German Expedition, Potsdam and Swedish Expedition (Markham, n.d.g., p. 90). Many elements were common to the German and British expeditions: new ships constructed as magnetic observatories, instruments, observing protocols and employment of trained civilian scientists to perform the work. The locations of the two vessels were planned to be complementary during the observing period and the regime was established to ensure global synchronous observations across the world.

In spite of these arrangements the collaborative relationship regarding magnetic science between the expeditions broke down in the synchronous observation strategy and post-expedition data sharing. The same was not true for the meteorology where the data was shared effectively. Although collaborations are not vital for scientific success of an expedition, the potential value of such an arrangement is significant.

**7.2.7 Recruitment, training and development of skill and knowledge**

The recruitment of experienced, well-qualified staff and arrangements for their training and pre-expedition preparation are success drivers of prime importance to outcomes. Bernacchi was recruited at the last minute, allowing little time for training and familiarisation with the instruments and protocols. The error in his timing of the synchronous term hour observations can be attributed to the late recruitments as much as, in different circumstances he would surely have become familiar with the correct protocols and detected the error published in the *Antarctic Manual.* In his narrative Scott praised the work of the officers in a general statement: “It has been recognised that each officer in his department has added something to the advancement of scientific knowledge” (Scott, 1905b, p. 76) but this was written well before any data or collections had been analysed. Training of the ship’s officers at Kew should have provided Bernacchi with understudies for the Antarctic observations, but they were under-prepared.

Bernacchi was a good choice as physicist, but some of the physical science outcomes could have been superior if (William) Shackleton had remained. This was about logistics, not skill of the observer, except in the case of Shackleton’s forte, spectroscopic photography. Bernacchi would have been available on board to manage the Lloyd-Creak instrument that caused Armitage great trouble. Shackleton had visited Potsdam for training and would have been in contact with Bidlingmaier and would have known that the start date for the synchronised term hour observations was 1 March 1902, not 1 February (Longhurst, 1901a).

The most reliable magnetic data from the expedition was procured by Bernacchi at the ice station and, although not perfect for instrumental reasons, that data underpins the bulk of the official scientific reports. His informal training at Melbourne observatory, then his experience in Antarctica on the *Southern Cross,* then working up his results for publication, all provided a sound foundation for his *Discovery* work. The absence of a physicist on *Discovery's* outward journey to New Zealand represented a missed opportunity.

The selection and training of the civilian scientific staff was not a reflection of the high profile and expectations of the expedition and could be considered a second string team. Bernacchi was unqualified although well trained and experienced, and Ferrar was a green, recent graduate. Wilson made errors in identification of birds: a supposed area of strength and interest, and the bulk of his collecting was from lower latitudes. Murray proved himself to be short in leadership skills and ignorant of sciences beyond his own discipline. Scott's scientific leadership was at best benign, neither hampering nor really promoting the intellectual climate of the scientific team. Hodgson was the stand out with experience and training, but his potential was entirely quashed by logistic decisions. Koettlitz was the best of the scientists in terms of long field experience and capability, but he never followed through to publication. The officers (especially Armitage and Royds) had to fit scientific observations into their already onerous responsibilities and errors in the first meteorological volume confirm that Royds was not fully engaged with the end to end process, though this was no fault of his. These men worked diligently, but the expedition as a whole would have been better served by some different recruitment choices, especially in scientific leadership, such as Gregory and Bruce for example, both of whom were actively kept away from the expedition.

In the context of deficient instructions, challenging instruments and a scientific leadership vacuum the selection of scientific staff was critical. In a physical science program, the instruments, the performance of observations and adherence to protocols are the nub of quality outputs. In the case of natural sciences such as geology, the calibre of the scientist is more directly related to output, as decisions about sampling during fieldwork require on the spot judgement. A poor choice of scientist can ruin the prospects for any research program, but a meticulously planned and well-directed program can accommodate for shortcomings in staff skill or instrumental deficiencies by planning for all contingencies. There is a rare exception that counters this argument about recruitment choices and training strategies being critical to outcomes. Bidlingmaier's magnetic assistant on *Gauss*, Lenart Reuterskjöld (1882-?) was a competent and valuable magnetic observer and assistant, yet he was a last minute addition to the crew in Capetown. Bidlingmaier and Reuterskjöld alternated magnetic hut duties each six hours and the sailor had sole charge of the magnetic observatory during Bidlingmaier's month long sledge journey. There was no recruitment process or formal training, yet he proved to be an important team member and contributor to the scientific program (Drygalski, 1989, p. 31).

### 7.2.8 Equipment and instruments

There were three categories of instruments used on the expedition. The highly accurate, observatory-quality instruments installed in the purpose built observatory huts at Winter Quarters. These were the Kew pattern monofilial magnetometer and the Eschenhagen variometer and clockwork drum apparatus. On the *Gauss* a balance wheel in the mechanism of the Eschenhagen apparatus split from the extreme cold, but repairs were made after which no further difficulties were encountered (Drygalski, 1989, p. 165). These instruments were suitable for the task and matched those used at the established global observatories.

The second category was instruments for observations at sea. The Lloyd-Creak dip circle was the primary instrument and it was developed especially to collect the data for dip and magnetic intensity. Like the Eschenhagen, it was developed shortly before the voyage but it had not been tested in its normal working environment, a moving ship. It had deficiencies and the results were unreliable, causing them to be mostly excluded from the final results. The results that were included were from high latitudes only, presumably inside the fringing ice pack where wave motion and therefore ship movement is damped. The Lloyd-Creak circles were in common use in later expeditions, but only in the form modified by the Carnegie Institution in Washington, D.C., and primarily for terrestrial observations.

The third category is the set of instruments provided for use on sledge journeys. Aside from the pocket compasses, Barrow dips were called into service for the sledge journeys where magnetic science was a priority (Armitage's western journey and Bernacchi's Barrier journey). These devices hardly raised a mention in any diaries, narratives or reports, as they were familiar. The Barrow dip, an older, more reliable style of instrument became the fallback at sea, but it lacked the facility to take direct measurements of magnetic force.

The impact of inadequate instruments was fatal to the prime objectives of *Discovery's* magnetic force observing program at sea. The flow-on to published results is self-evident. Instrumental error, mostly related to Bernacchi's absolute observations and the labile nature of the traces that ran off the scale of the photosensitive paper, led to exclusion of large amounts of data from the Winter Quarters.

### 7.2.9 Logistics

Logistics choices regulated opportunities for scientific work at sea and on the ice. Melbourne was to have been established as a magnetic base station and the observatory facilities and Bernacchi's mentor, Baracchi were intended to assist in calibrating the ship's instruments. The decision to bypass Melbourne was made to ensure that the magnetic observations at sea at a high latitude below Australia, close to the point of maximum magnetic intensity, were possible. Potentially unique and valuable data from that point could have been procured, but its omission from the scientific reports indicates its unreliability. The change of schedule that took *Discovery* direct to Lyttelton (Christchurch) had the positive effect of introducing Farr and Skey into the workings of the expedition. Their contribution was notable before, during and after the expedition, but it obliged construction of a new observatory. The instructions to the commander specified landfall at either Melbourne or Christchurch, not both, and it's unclear whether Scott always intended to go via New Zealand irrespective of the Melbourne plan. Slow progress of the ship diminished opportunities for oceanographic, dredging and trawling activities.

The logistic decision to overwinter the ship in Antarctica in 1902 had a number of repercussions. A comfortable, safe haven was provided allowing scientists to focus on their work and less on matters of survival as would have been the case in hut life. The availability of crewmen to assist with functions like construction of the magnetic observatory huts, auroral observations and the provision of manpower on sledging journeys might have been restricted if the ship had retreated north after establishing a land party. The conditions that Bidlingmaier worked under at the *Gauss* ice station were severe compared to Bernacchi's Winter Quarters observatory and the results were as good, or better. This indicates that the magnetic program could have succeeded if the *Discovery* landed a party for the winter. Coastal exploration and oceanography were diminished by the decision to overwinter the ship in Antarctica but: "If they had not determined to use the ship as a house boat, the information as to the continent would not have been obtained through our exertions" (Darwin, 1931). There is no explanation why no further use was made of the ship's magnetic observatory during the stay in Antarctica although Royds states that non-magnetic phosphor bronze stoves were installed for winter heat to allow observations to continue (Royds, 2001, p. 177).

The logistics related to sledging journeys were mostly about exploration, not science. Scott supported Royds and Bernacchi's Barrier journey, whose objectives were exploratory, glaciological or magnetic, depending on whose account you read. In general, science was interwoven into the agenda for exploration, not vice versa, so logistics did not necessarily favour the needs of individual scientists like Hodgson and Ferrar. Koettlitz undertook his research mostly on base, so was unaffected. Wilson lamented his selection for the southern journey as he correctly surmised there would be no wildlife but he did make a valuable contribution to the geographical record by drawing the landscapes presented by the mountain range and Mulock's observations from his 1903 southern journey fixed many landmarks more accurately.

The logistic choice that resulted in *Discovery* being icebound for two years was advantageous to the physical science and meteorology programs. The trade-off was diminished results in oceanography, trawling and coastal exploration. The unpredictability of scientific work in the Antarctic and the short field season still mean that logistics choices must be made on the fly and the right decision can be a matter of survival of the scientific crew. The impact and significance of logistic choices varies according to the scientific discipline and nature of the scientific inquiry, and whether the work would generally be carried out at sea, on base or in the field.

### 7.2.10 The work of the scientist

Magnetic science at sea was carried out diligently but ineffectively due to the combination of inadequate instruments, the ship's characteristic heavy roll, the shifting of the tinned provisions below the magnetic observatory and the absence of a scientific mentor. The ship was well found magnetically (the deviation values were small) but factors did not align to allow good results. The declination (variation) results found in the scientific reports could have been procured on any ship with correctly adjusted compasses. Armitage confines his closing comments in the appendix of his narrative to the magnetic variation, and does not mention the dip and force data: "The observations for variation have proved very good, and the results of these alone are sufficient reward for all the monotonous labour connected with the magnetic observations at sea" (Armitage, 1905, p. 304). The manner in which magnetic science was performed at sea was a significant limiting factor on outcomes, but only in the context of the other elements that needed to converge to provide suitable observing circumstances.

The practice of magnetic science at the Antarctic base met or exceeded expectations. The observations derived from the continuous recording Eschenhagen magnetograph and the Kew magnetometer were the cornerstones of the physical science reports of the expedition. Fixing the location of the magnetic pole was mainly possible from data obtained from the sledging journeys and aboard the ship within the Ross Sea. This data was enhanced by the dip and intensity readings from Winter Quarters. The objectives of the expedition did not include a bid to actually reach the magnetic pole and neither of the western sledge journeys had the range to do so. Dip circles were taken on only two of the sledging traverses, Armitage's western mountain trek and Bernacchi's Barrier journey. Most of the deviation observations on other sledge journeys were made with the aid of pocket compasses, making them a lower order of reliability. The small size of the instrument increased potential reading error and the proximity of the magnetic pole made compasses sluggish due to the low horizontal magnetic force. Drygalski's pocket compass observations of declination were: "impossible with this instruments as it was too sluggish, and there was too much friction for it to react to the variations, given the weakness of the horizontal force in polar latitudes" (Drygalski, 1989, p. 144). Royds described his pocket compass observations as "comparatively useless" (Royds, 2001, p. 175).

There is no fault with the performance of the magnetic observations by Armitage or Bernacchi. Both did more than required for successful outcomes. The instrumental difficulties, along with a scientific leadership vacuum in physics undermined their efforts. If all other contributing elements driving the science are positive, then the actual performance is a lower order of importance as a driver itself. A skilled technician could produce acceptable outcomes if other circumstances wer favourable.

### 7.2.11 Social and intellectual landscapes

The diaries and narratives of the expedition do not effectively convey a picture of the intellectual landscape. Aside from the occasional scientific debates in winter, the lectures presented for the education of the lower deck and some articles in the *South Polar Times* that described scientific work, there are no hints about the frequency or vigour of scientific debate. On the passage out to New Zealand, Armitage was acting almost alone as magnetician but may have discussed the operations with Barne, who was less experienced. On the ice Armitage and Bernacchi had common knowledge of the magnetic work but there is no record to indicate they discussed or debated any of the physics. In general, the social climate was harmonious, so the development of a vibrant intellectual landscape was possible. Comments about Scott's willingness to engage with the scientists are mostly in reference to his second expedition.

A hallmark of good science is the formulation of the right questions, whose investigation leads to novel outcomes, a process promoted by the creation of a vibrant intellectual space. The *Discovery's* magnetic science program at sea and in Antarctica was a mildly intellectually challenging enterprise confined to a series of data collecting procedures. There was no freedom to really develop new questions or approaches to their solution in the case of magnetic science. The instructions and the spatial and logistical limitations confined Bernacchi and Armitage to the perpetuation of Sabine's simplistic data collection and aggregation paradigm.

Scott and Shackleton both became freemasons prior to their departure on *Discovery* (Huntford, 1985, p. 42). This was a strategic career move as Markham's cousin, Admiral Albert Markham (1841-1918) had established the Navy lodge in 1896, and it was a place where ambitious officers could make contact with their superiors away from the hierarchy of the RN. The lodge was populated by many high ranking and decorated naval officers and senior civil servants, and HRH The Prince of Wales was the lodge's first Master (Navy Lodge No. 2612, 2013). This relationship says little about the intellectual climate of the wardroom in Antarctica, but the civil relations between Scott and Shackleton in public, above an undercurrent of ill feeling after the expedition may be attributed to it (Barczewski, 2007, p. 49).

Vibrant social and intellectual landscapes on expeditions promote scientific outcomes, but are not critical. Individuals may shine, even under adverse conditions. Bernacchi did so on the *Southern Cross*, in spite of the uncomfortable social landscape under Borchgrevink's poor leadership.

### 7.2.12 Serendipity

In the *Physical Observation* report, Chetwynd notes that: "the magnetic conditions were largely affected by local attractions" (Chetwynd, 1908, p. 134). Detail from a modern chart of magnetic intensity for the Ross Island locality (Figure 13) shows that Hut Point (at lower right hand corner of image) is an area with a steep magnetic intensity gradient. The chart shows low intensity in blue and high intensity in purple, with an overlay of isodynamic lines (lines of equal magnetic intensity). By chance, Bernacchi established his Antarctic observatory in an area where local anomalies added significant signal noise on top of the magnetic signature generated by the earth's internal dynamo and perturbations from space weather. Chree described Winter Quarters as a region of appreciable local magnetic disturbance and mentioned the significant differences between the observatory data and the data from the tent established briefly on the sea ice, far from land with its influencing volcanic rock. He concluded on a positive note: "there would not be much reason to fear anything more than a reduction in declination" (Royal Society, 1909, p. 88).

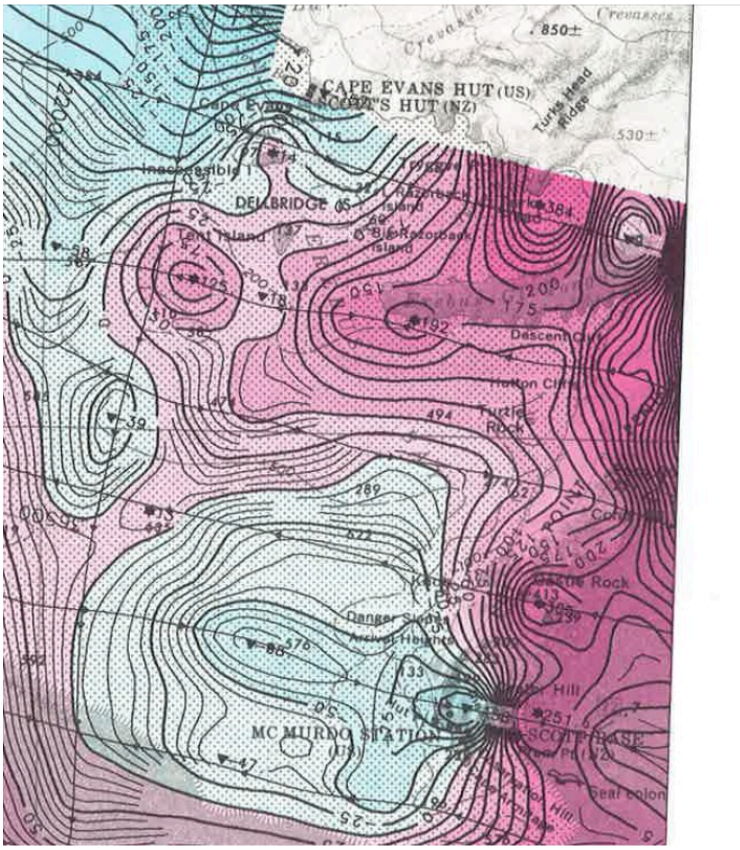


Figure 13: Detail of magnetic intensity in the locality of Ross Island (Damaske & Behrendt, 1996).

Bad luck can be fatal to a program of research or exploration. Mawson’s AAE Western Party under Frank Wild’s leadership (1873-1939) took a risk and constructed a hut on an ice shelf that survived their year’s sojourn. Filchner did the same but the hut was destroyed by the collapse of the ice almost immediately after construction was complete. This may have been more poor judgement than bad luck, but it demonstrates the fragility of survival and work in the era of early polar expeditions.

Scientific and geographical outcomes can turn on chance events like the detection of mosses at Granite Harbour, discovery of the Dry Valleys by Scott or Barne’s determination “almost by accident” that a depot on the ice barrier moved 608 yards (556 m) seaward in thirteen and a half months (Scott, 1905b, Volume II, p. 300). Another exception piece of good luck was discovery of fourteen undigested specimens of a new species of fish in the gut of a seal butchered for food (Skelton, 2004, p. 188). The discovery of Scott Island in the mouth of the Ross Sea by the *Morning* on 25 December 1902 was also pure chance (Conrad, 1999, p. 115). Priestley wrote: "Such is the romance of polar science, and so dependant upon the merest chance its results may be" (Priestley, n.d., p. 7).

### 7.2.13 Post-expedition handling and publication of data and collections

Post-expedition management is critical to the full cycle of scientific process. The example of errors in the first meteorology report demonstrates how the effort of the field observers can be completely squandered in the absence of post–expedition collection supervision. During the Edwardian era it was commonplace for official scientific reports to take many years to develop and Bernacchi's estimate that it would take at least two years was optimistic, even assuming his involvement as a sub editor. The *Physical Observations* volume was published after four years and the *Magnetic Observations* after five. These compare well with the publication of Drygalski and Mawson's magnetic reports, both in 1925.

The scientific leadership vacuum evident at sea and on the ice became more pronounced after the return of the expedition. Neither Markham nor Scott had remained involved with the post-expedition work, and this is especially evident in the case of the meteorology reports (Yelverton, 2000, pp. 409-413). An earlier example of poor post-expedition management is the case of the loss by Borchgrevink of the zoological notebooks written by Hanson, who perished at Cape Adare (Crawford, 1998, p. 207). His collection was valuable as the scientific record from the first overwintering party on the mainland of Antarctica, but diminished in its potential due to the negligent loss of the collecting notes.

In *Discovery's* case there was considerable confusion as to where the magnetic data would be sent, who had intellectual ownership of the data, and who would reduce, analyse and publish on it. It is fortunate that the magnetic results were handled well by Chetwynd of the Admiralty, and Chree of the National Physical Laboratory. Gregory's original plan was to have a committee directing post-expedition arrangements (Gregory, 1900a) in which case some unfortunate events may have been avoided. Koettlitz had a falling out with Ray Lankester, Director of the BMNH and as a consequence walked away with his collection and records that were never seen again. Two years of bacteriological work in the Antarctic was lost and never published because no one was overseeing the post-expedition arrangements, and it was only by chance that Hodgson made an inquiry about the progress of the work that brought the debacle to light (Hodgson, 1908). Koettlitz believed the civilian scientists were all treated in a shabby manner, being given no voice as to their own collections: "I am quite of the same mind as you with regard to disgust as to the way we of the scientific staff have been treated, as of the unfairness of the contrast between Capt$^{n}$ Scott's treatment and ours…" (Koettlitz, 1905).

Neither Scott nor Royds saw the first meteorological report before its publication. Many of the errors contained within the volume could easily have been rectified by Royds' involvement during production, or at least a final chance to proof read the work (Markham, 1908). Scott did not live to see the erratum notice in the introduction to the second volume and he would have been disappointed it did not satisfy his demands to put right what he regarded as a slur against the observers, in particular Royds. Likewise, Scott had not seen the *Magnetic Observations* volume prior to its publication then review in the newspaper (Scott, 1908c). Opportunities for better outcomes from the *Discovery* science publications were squandered as a result of dislocation between collector and analyst and the poor post-expedition management of data and collections. In contrast, quality outcomes were produced from Mawson's AAE and Drygalski's *Gauss* magnetic research. Webb, the magnetician on Mawson's AAE wrote more than half of the scientific report on *Terrestrial Magnetism* (Webb, 1925). Drygalski oversaw the publication of all the *Gauss* scientific reports, twenty in total, plus two atlases. Bidlingmaier and Karl Luyken (1874-1947), the magneticians on the *Gauss* and at the Kerguelen Base station respectively, wrote the major parts of the German terrestrial magnetism reports (Rosove, 2001, pp. 108-122). Bernacchi recorded the German post-expedition arrangements in his diary:

> Dr Luyken-the German who was in charge of the magnetic work on Kerguelen Island in 1902 lunched with me at the club. Told me of the arrangements made in Germany for reduction and publication of scientific work conducted on the *Gauss* Expedition. Infinitely better than ours-A special Antarctic office has been established in Berlin [illegible] & the head of each department … has charge of his own work with his assistants under him… Will take about 5 years to complete-there were nearly double the amount of observations- they propose to do it in a little over 1 year.
>
> (Bernacchi, 1904)

In spite of the logistical effort put into the sledge journey to the region of the magnetic pole during Shackleton's *Nimrod* expedition, no volume devoted to magnetic science was ever published. Shackleton engaged Mawson as he needed a physicist, but Mawson was a geologist. Mawson made some contributions to the geological papers within the science reports (Rosove, 2001, pp. 389-390) but magnetic science from the *Nimrod* expedition is reported only briefly as part of Mawson's AAE *Terrestrial Magnetism* report (Webb, 1925, pp. 50-52). On *Discovery* there was a slight shift away from the entrenched "metropolis and periphery" intellectual tradition of handling materials and, for the magnetic science, this arrangement probably led to the best publication outcomes as the observers were not theorists and may not have recognised the significance of novel results.

As a driver of scientific success, post-expedition management of data and collections then fostering publication are critical irrespective of the quality and quantity of materials and data gathered. This important element of the scientific program on *Discovery* was not planned and then, although Markham controlled the dispersal of all the scientific intellectual capital of the expedition by settling agreements for others to analyse and publish on it, there was no adequate follow through after the ship returned to England.

A framework of criteria for future assessments of historic polar or frontier science programs has been established and tested in this chapter by review of the elements of the magnetic science program on the *Discovery*. Conclusions about the scientific successes and failures of the expedition, and a ranking of the impact and importance of their drivers follow in the closing chapter.

# Chapter 8: Analysis of *Discovery's* scientific outcomes

Debate about definitions of successful expeditions and their scientific research programs is not a new phenomenon. Bernacchi mentioned wardroom discussions on the topic in May 1903:

> Some interesting arguments have taken place in ward room lately. One yesterday dealing with the meaning of the "success" of an expedition + an explorer 'ideal' (whatever that is).
> Some contend that an expedition was not a success unless it fully carried out its original plans + others that it was equally successful if it failed in its original plans but accidentally or otherwise made equally important discoveries etc. It was all very absurd…
>
> (Bernacchi, 1902c)

Conclusions about *Discovery's* success and whether it achieved the potential of the scientific program in terrestrial magnetism form the core of this chapter.

## 8.1 Achievements & Successes

The report of Bernacchi's 1908 lecture to the British Association for the Advancement of Science provided the best synopsis of the main findings of that magnetic work. It was delivered when publication of the two physical science volumes was imminent and it clarified the main findings that were difficult for the non-scientist to comprehend. The points were:

- Observations at Winter Quarters were carried out over a two-year campaign
- The average declination for that location was about 152° E.
- The regular diurnal range of declination is five or six times as large as found at the Kew observatory
- Even when the sun is continuously below the horizon the diurnal range remains at least twice the values found at Kew
- The seasonal change in the type of variation is very small

- There was no notable difference between changes in declination from day to night, unlike in temperate climates, where daytime changes are conspicuously larger and more rapid
- The horizontal force at Winter Quarters was about a third of that observed at Kew but the range of diurnal inequality was about 50 % higher
- The vector diagrams for the magnetic elements are much less symmetrical in Antarctica than at Kew, the direction of motion is anti-clockwise and there is little difference between seasons
- A striking feature of the diurnal inequality in all magnetic elements is the large size of the fundamental Fourier wave with a twenty-four hour wavelength
- Declination observations at Winter Quarters, on sledge journey and at sea combined to place the magnetic pole in a locality about 72° 50' S, 156° 20' E. The inclination observations give close agreement.

(American Geophysical Union, 1908)

The alignment between instructions and outcomes for the magnetic science program are reviewed at section 7.1.1., but to expand understanding of the significance of *Discovery's* other results, a comparison of expectations embedded in the instructions (British National Antarctic Expedition, 1901) against achievements in exploration and other science disciplines follows:

- <u>Instruction:</u> Whenever possible while at sea, deep sea sounding should be taken with serial temperatures, and samples of sea water at various depths are to be obtained, for physical and chemical analysis. Dredging operations are to be carried on as frequently as possible, and all opportunities are to be taken for making biological and geological collections.
  <u>Outcome:</u> This was not successful. Kilometres of sounding wire, often with Pettersson bottles and thermometers attached (over 8,700 fathoms or 15,900 m), were lost during four soundings in June-July 1904. The scientific operations listed were infrequent at sea (Skelton, 2004, pp. 208-211).

- <u>Instruction:</u> It is desired that the extent of land should be ascertained by following the coastlines, that the depth and nature of the ice cap should be investigated, as well as

the nature of the volcanic region, of the mountain ranges, and especially any fossiliferous rocks.
Outcome: A nominal amount of new land (150 miles or 240 kilometres) was detected by coastal survey from the ship but charts of known coastline were improved by Mulock's accurate charting of the western coast of the Ross Sea (Hayes, 1928, p. 144). New coastline was discovered on sledging journeys on the Ice Barrier and on sea ice that bordered the coast. Scott's plan for *Discovery* to investigate coastal areas to the west of Cape North was hampered by lack of coal on the return journey. There was no technology available to make measurements of the depth of the ice cap, but snow pits were dug and samples taken to attempt characterisation of the overburden. Plant fossils were discovered, but their exact nature could not be determined.

- Instruction: explore the Ice Barrier of Sir James Clark Ross to its eastern extremity; to discover the land that was believed by Ross to flank the barrier to the eastward, or to ascertain that it does not exist; and generally to endeavour to solve the very important physical and geographical questions connected with this remarkable ice formation.
  Outcome: Successful work was done on this matter. King Edward VII Land was discovered at the eastern end of the Barrier and Borchgrevink's finding that the Barrier had receded significantly since Ross was confirmed. The flow of the Barrier from the coastal ranges towards the sea was confirmed and the fact that it was afloat was also supported.

- Instruction: If the ship is overwintered in the ice then three main objectives for geographical exploration are noted: advance into the western mountains, an advance to the south and exploration of the volcanic regions.
  Outcome: All these were successfully acquitted.

## 8.2 Failures and unmet expectations

During gestation, every element suggested the *Discovery* expedition could and should have represented best practice in Antarctic scientific research prior to the Great War if compared against the measures of quality, productivity, new knowledge generation and the achievement of outcomes against objectives. The results for the magnetic research fell short of expectations in all these key elements and accurate location of the magnetic pole, the reliability of data gathered both at sea and ashore, the utility of data sharing with the German expedition and publication of charts for mariners.

Where is the evidence to support Yelverton's statement that the magnetic pole was located: "certainly well enough to build the magnetic map of the Southern Hemisphere" (Yelverton, 2000, p. 311). There is none, as data from one expedition and just a handful of southern hemisphere observatories are insufficient to build such a chart and, with respect to magnetic observations, no point on the globe is especially more important than any other (Cawood, 1979). Also, the position of the magnetic pole determined from *Discovery's* data was thrown into serious doubt by the findings of Mawson's AAE results. Webb's *Terrestrial Magnetism* report specifically mentions the outcomes determined by Chetwynd in which he located the magnetic pole at 72° 51' S, 156° 25' E, or 167 miles (269 km) from the position determined by Mawson's own expedition (Webb, 1925, p. 55). Mawson's magnetist, Webb, was well trained as a field observer by the Carnegie Institution of Washington and as an operator of the Eschenhagen magnetometer by Dr. J. M. Baldwin (1878-1945) of Melbourne Observatory (Webb 1965, p. 2). The expedition used the improved derivatives of the Lloyd-Creak dip circle, modified by the Institution in the light of difficulties encountered by Bernacchi and Bidlingmaier. Webb commented on the accuracy of the *Discovery* result:

> Since the values of D and I, on which Commander Chetwynd's charts were based, were confined almost exclusively to one side of the Magnetic Polar Area, there is room for considerable uncertainty in conclusions regarding location of the Pole … location by intersection of magnetic meridians is of little account unless a large number of determinations on at least three sides of the Magnetic Pole Area are available.
>
> (Webb, 1925, pp. 55-56)

Webb later wrote in memoirs that Farr of the Canterbury Observatory believed that his (Webb's) location of the magnetic pole to be the most accurate of those made during that epoch (Webb, 1965, pp. 9-10).

There was sufficient reliable data to support the production of extensive magnetic reports and the bulk and density of those can mislead readers into believing that the *Discovery's* research met expectations. This research has shown it fell short of potential. Chapter seven above details the extent of data considered unreliable, the failure to publish data on magnetic force at sea, rejection of the bulk of absolute magnetic measurements from Winter Quarters, the proportion of magnetograms considered unreliable as a consequence of the failure of absolute observations and the trace running off scale, the failure of collaborative data sharing with Drygalski, the error of timing of the term day observations and numerous other incidental faults and shortcomings. Difficulties with the instruments undermined the value of the ship as a floating magnetic observatory and the expectation that there would be commercial value through new magnetic charts was never realised. The prospect that sufficient new material would come to light to progress theory of the causes of terrestrial magnetism also went unrealised.

The American meteorologist Matthew Fontaine Maury (1806-1873) provided an example of how massed data from at-sea observations could be put to good effect by producing charts of seasonally reliable wind patterns for the use of sailing masters. An example is his *Sailing Directions for the Atlantic* that provided tangible economic benefits by shortening average sailing times on major trading routes (Halford, 2005, p. 99). The magnetic equivalent, complete revision of magnetic charts for the southern oceans anticipated by Markham was never realized. Neither was the development of new theories of causes of terrestrial magnetism. These were both unrealistically ambitious expectations touted by Markham to gain support at the beginning of the expedition.

## 8.3 Opportunities squandered?

Failure to take advantage of opportunities that presented themselves before, during, and after the expedition contributed to the failure to meet expectations in the magnetic science and in other disciplines. A central facet of the magnetic observation program was squandered by not testing the Lloyd-Creak Circle at sea, by recruiting Bernacchi so late that he could not join the ship on its outward passage, and by not offering Armitage opportunities to practice with the instrument away from observatory conditions.

Collaborations could have been forged with a broader range of magnetic specialists. Bauer was one of the leading magnetists in 1900, but there is no record of any attempt to consult or collaborate with him. Mawson subsequently worked with Bauer in preparation for his AAE, arranging for the Carnegie Institution's Department of Terrestrial Magnetism to train Webb, and for the loan of instruments. There was also missed potential for additional magnetic observatory data:

> Prof. Dr Eschenhagen drew attention, with regard to international cooperation, to the fact that the United States had planned the establishment of three complete observatories at Washington, in Hawaii and in Alaska. The establishment of these might be accelerated if the desire of the Committee that they should be made available for co-operation at the time of the Polar expeditions were brought to the notice of the United States by the Imperial Government.

(Minutes of Sub-Committee of the [German] Scientific Council for Meteorology and Terrestrial magnetism, 1899). In Sweden, Birkeland was preparing for his Arctic auroral observatory research that included magnetic surveys. His findings were included in the *Magnetic Observations* volume but better value from shared observing methods might have been possible. If the RS had been more closely involved with preparations for the expedition, these important connections with world leaders in the discipline might have produced positive outcomes for partners.

How would the outcomes have been different if Gregory remained scientific director of the civilian staff and his plan of operations had been followed? It's probable that the Lloyd-Creak circle would have been tested at sea and improved before the expedition left. The collaborative scheme of data sharing might have come to fruition, allowing deeper interpretation and advances in theoretical knowledge from truly global data. The post-expedition management of collections and data would have been planned in advance and not executed in the haphazard manner that transpired. Melbourne might have been the base station, and even if not, observations from there may have added to the global data set. Different transport strategies using dogs might have resulted in longer and more scientifically significant sledging journeys from the winter base.

There are additional instances of squandered opportunities not directly related to magnetic sciences that stand out. Markham's disregard of opportunities to purchase an existing ship, such as the offer of *Diana* from Kinnes of Dundee for £3,600 in 1899, and his insistence on the construction of a new vessel was a folly, probably motivated by national pride and the desire to leave a tangible legacy. The time and energy expended in management of construction may have been better spent on preparations for science and exploration. This research concludes there is no direct relationship between cost of the expedition vessel and scientific success. The carnage of the land rail population on Macquarie Island was in vain. The target species was endemic, rare and collectible, but in error, the species collected was another, the New Zealand weka, that had been introduced to the island (Skelton, 2004, p. 29).

There were some instances of missed opportunities for investigation that might have been considered low hanging fruit, scientifically. Bernacchi was busy with Milne's seismograph within a few days march of an active volcano. Surely it crossed the minds of

Scott, Ferrar and others that an ascent of Mount Erebus would advance science at a cheap investment of time and effort. On the Barrier journey, Royds had sterile tubes for collecting and sealing Antarctic air samples. It might have been a coup to use the procedure to collect a sample of gas from the crater's mouth. Why disregard the opportunity and leave the glory for others to achieve? Another squandered opportunity was the scientific output lost with the failure to deposit Koettlitz's microbiological collections at the museum or to publish any results in that discipline. This was a direct consequence of the failure of post-expedition management of collections, another example of the institutional failure by management of the expedition.

Wilson and Koettlitz squandered opportunities for research into human biology. Men of the *Discovery* were under extreme levels of physiological and psychological stress. They knew that Hanson had died during the *Southern Cross* expedition, mental health issues had emerged during the *Belgica* expedition and it transpired that the *Gauss* expedition base-station (Kerguelen) and relief voyage members died of beri-beri (Headland, 2009, p. 233). Aside from taking blood samples for performing cell counts, and the monthly physical measurements, no further studies were made. It was an ideal opportunity for a comparative nutrition study along the lines of that performed during the *Terra Nova* Cape Crozier emperor penguin egg collection journey of 1911 when the three men tried different diets, each loaded with constituents of standard sledging rations: protein, fat or ship's biscuits. Better knowledge of nutritional requirements for sledging parties was critical information for later extended overland journeys. Koettlitz explained to Hodgson that he had left the notes on blood and physical examinations of the men in Dover when he migrated to South Africa and it might be possible to recover them (Hodgson, 1909). Wilson lectured to the British Medical Association in 1905 providing a descriptive account of nutrition, the appearance of scurvy, clothing, exercise and the privations of sledge travel and harsh weather. He stated that "All the bacteriological work, however, was done by Dr Koettlitz and his results will no doubt appear in dure course" (Wilson, 1905).

Overwintering the ship represented diminished opportunities for dredging, trawling and oceanographic work, as well as further coastal exploration. The majority of species richness in the Antarctic is in the benthic fauna and the total macrofaunal richness of the continental shelf may exceed 17,000 species (Clarke, 2008). Confining sampling to the locality of Hut Point peninsula severely limited Hodgson's opportunities. In contrast to *Discovery*'s meagre sample of only ten species of fish, four of which were new to science, the *Terra Nova* expedition discovered 17 new species and seven new genera (Priestley, 1914).

If the *Discovery* had not overwintered and more sounding and deep-sea temperatures had been possible, scientists from the expedition might have recognised the phenomenon of the Antarctic convergence, or polar front. Wilhelm Meinardus (1867-1952) recognised its existence and published his finding in the meteorological volume of the *Gauss* scientific reports (Fogg, 1992, p. 198). *Discovery* was potentially well placed to reveal the phenomenon, but in fairness, the *Challenger* was better placed, but also missed this important feature.

The *Antarctic Manual* contained only nine pages of information on glaciology and sea ice yet the extent of ice and the presence of impressive glaciers in the Victoria Land quadrant were well known to expedition organisers. Glaciology was a developing scientific discipline of the time and Louis Agassiz (1807-1873) had advanced the discipline considerably during the nineteenth century (Fogg, 1992, p. 248). No ice specialist was included amongst the civilian scientific team.

## 8.4 Comparison against contemporaneous expeditions

This research has revealed numerous flaws in the magnetic science on *Discovery* and it is reasonable to speculate in conclusion whether a similar range of previously unrecognised failures are hidden for other expeditions. Development of a thorough and objective comparison between *Discovery* and similar expeditions of the era is outside the scope of this research due to the unmanageable volume of additional investigation required, but some commentary is warranted. Throughout the course of the research sources related to scientific work on other expeditions have been consulted, so it is reasonable to draw some tentative and somewhat subjective conclusions that attempt to satisfy the perennial question of how the expeditions rank in terms of scientific success. This research has shown the drivers of scientific success are complex, numerous and unequal in importance and impact. A ranking of expeditions is possible with the aid of a scaffold of drivers of scientific success. A legacy of this analysis may be assistance to later researchers who wish to build on this research by developing objective and accurate analyses of science on expeditions other than *Discovery*. A brief commentary on scientific outcomes of selected expeditions follows.

Drygalski's *Gauss* shared many characteristics with *Discovery*. Both were created and managed by institutions rather than by individuals. Government sponsorship provided funding for both, although *Discovery* also had significant philanthropic contributions. Both expeditions had custom built vessels with magnetic observatories as a central feature. Drygalski's expedition had a historic context framed by Germany's leadership in magnetic research through the nineteenth century, but did not suffer from the impositions of RN traditions. Drygalski recruited Bidlingmaier who was a scholar of magnetic science and who performed the magnetic research above expectations. Drygalski, a scholar with expedition experience provided scientific and expedition leadership and the quality scientific outcomes is a reflection of his personal agenda. Geographic outcomes were modest, a consequence of circumstance rather than a trade-off that balanced science against exploration, as was the case on *Discovery*. *Gauss* had the same suite of magnetic instruments as *Discovery* and encountered similar difficulties, mostly overcome by Bidlingmaier's efforts. A particular strength of the *Gauss* expedition was the ongoing post-expedition management of the data and collections, and preparation of publications that extended through the years of the First World War and continued until 1931. Contributions of the scientists are abundant throughout the official scientific reports. They are: "a striking testimony to the scope and quality of the science performed on the expedition" (Rosove, 2001, p. 108). Drygalski's outcomes are generally regarded to be the best of the 1901-1904 Antarctic campaign.

Bruce gave solid expedition and scientific leadership to the *Scotia* expedition team of accomplished scientists. As the first Scottish national expedition there was no guiding intellectual tradition. Many individual research papers were published in journals before their appearance in the seven official scientific reports (Rosove, 2001, p. 50). The expedition did not achieve remarkable geographic results but the focus was on scientific work not exploration. There was some collaboration with Argentina who took over the observatory site and maintained it as an ongoing meteorological recording station. One facet of Bruce's superior leadership was his post-expedition management of materials and data, fostering their preparation for publication.

Shackleton's *Nimrod* expedition had a primary focus on exploration. He was aware that a scientific program was an essential part of establishing credibility with prospective sponsors, so there was a solid program focused on geology. There are five published volumes of scientific results, two each of biology and geology (including ice studies) and one on meteorology. No magnetic volume was published. Shackleton selected an interesting mix of scientists, choosing Priestley for his skill with the banjo rather than his geological knowledge, and taking the Australians Edgeworth David and Mawson as an afterthought (Tony Fleming, personal communication, 8 March 2011). These facts indicate that Shackleton was either not genuinely concerned about the scientific outcomes, or believed that non-specialist scientists could sufficiently cover other branches of science.

Scott's *Terra Nova* shared its contextual background with *Discovery* but many other characteristics were dissimilar. While the *Discovery* was well funded, the *Terra Nova* was mounted on a relatively slim budget and in spite of a focus on the attainment of the geographic pole the scientific program was robust. Scott was the organiser and leader, receiving nominal support from the RGS and RS. He was able to procure instruments on loan from the same sources as the *Discovery* and the recruitment of civilian scientists was less haphazard than the first venture as Wilson, appointed scientific director, had control of proceedings. The logistics were closer to the model that could have given better outcomes for *Discovery*. The *Terra Nova* landed a party for the winter before retreating north to deploy a second scientific party and carry out coastal exploration.

The magnetic program was almost identical to the *Discovery* protocols. The suite of instruments again included Kew and Eschenhagen magnetometers and on this expedition twenty-three observatories were synchronised to take a total of 36 term hour observations. Four of the dip circles were the same as taken on *Discovery*. The two Dover circles, Nos. 26 and 27 were used and Lloyd-Creak Circles, Nos 143 and 149, improved according to the Carnegie Institution's method, were also taken (Chree, 1921, pp. 429-430). An analytical method developed by Bidlingmaier was applied to characterise the diurnal disturbances (Chree, 1921, pp. x-xi). Like the *Discovery* results, the at-sea results include complete records for declination that are reported as "variation" in deference to Commander Harry Pennell's (1882-1916) contribution and preference. There are no results for magnetic force and only a handful of inclination measurements (Chree, 1921, pp. 430-449). *Terra Nova* had no magnetic observatory so there was probably no expectation on improvement of *Discovery*'s at-sea data. At Scott's Cape Evans base the absolute instruments were housed in an observatory hut, but the Eschenhagen apparatus was established in an ice cave to reduce the swings in temperature suffered by Bernacchi's instruments in the *Discovery* variation hut.

One outcome was determination that the magnetic pole was migrating in a north-westerly direction, consistent with data compiled from Shackleton's *Nimrod* and Mawson's *Aurora* expeditions and the long term trend since Ross, but at odds with Chetwynd's *Discovery* conclusion of a north-easterly trend (Mawer, 2006, p. 236). The abundance of the *Terra Nova* scientific reports is partly an artefact of the finance made available through public subscriptions to the memorial fund established after Scott and his companions perished.

Mawson's AAE, the *Aurora* expedition, was more successful than Scott's *Terra Nova* by almost any measure, and represents the pinnacle of scientific exploration of the era. Hayes concludes: "Lastly, Sir Douglas Mawson's results far exceed all others because he made the greatest inroad into the unknown with the finest scientific staff" (Hayes, 1928, p. 260). Mawson struggled to acquire sufficient funding and the expedition outcomes represented value against investment. Opportunities for science and exploration were maximised by deployment of three base stations (Macquarie Island, Commonwealth Bay and Wild's Western Base) and a well-planned scheme of sledging journeys. The expedition encountered bad luck, firstly by locating their Main Base in a funnel of icy winds coming off the polar plateau, then Mawson's own sledge journey was marred by death of his colleagues and his own near-fatal journey back to base. Mawson provided overall expedition leadership and the objectives were primarily scientific. The staff of civilian scientists was well chosen and well trained. Science was performed to a high standard using quality instruments, including modified Lloyd-Creak circles, and a sledge journey to the locality of the magnetic pole, approaching from the north, was undertaken by Webb, Bage and Hurley. Mawson eventually managed a deal with the government of New South Wales where he traded his archive material and scientific collections (now in Sydney's Mitchell Library and the Australian Museum) for the government's undertaking to fund and organise the publications. The reports were published over decades with the last meteorology report being produced in 1947 (Rosove, 2001, pp. 251-260).

Nordenskjold's *Antarctic* and Charcot's *Pourquoi-pas?* and then the *Français* expeditions were strongly focused on scientific objectives but are outside the scope of this research. The *Southern Cross* under Borchgrevink and *Deutschland* under Filchner were both plagued by the breakdown of interpersonal relationships and doubtful leadership. The *Kainan Maru* under Shirase was under-funded, poorly prepared, lacked a scientific program and had no relevant scientific expertise aboard. In summary, the most scientifically successful expeditions of the era (both in quality and quality of output and significance of results) were Bruce's *Scotia*, Drygalski's *Gauss*, Mawson's *Aurora* and Scott's *Terra Nova.* All these expeditions cost significantly less than the *Discovery*, making it true that: "The scientific results were a poor dividend for the capital invested, and other expeditions of the day were more profitable" (Jones, 1980).

## 8.5 Key figures: Markham, Scott and Bernacchi

Markham was motivated to recreate the glory days of RN Arctic exploration and possibly saw his role as similar to Sir John Barrow (1764-1848), Second Secretary to the Admiralty who oversaw the organisation of many expeditions. His legacy would be the re-establishment of the pre-eminence of England's profile as an exploratory and territorial force. In spite of the complex committee structure, Markham retained almost total control of all matters to do with pre-departure arrangements of the expedition. His will always prevailed through control of committees and his involvement in every facet of organisation, but this did not work to the benefit of the expedition at many levels. The potential contribution of eminent and experienced scientific leaders like Gregory and Bruce was squandered by Markham's priority of exploration at the expense of science. The RS withdrew collectively from the adversarial environment that developed once Markham no longer needed the reputation of the society or the scientific program as fundraising levers. Many elements of the expedition were modelled on obsolete or irrelevant strategies. *Discovery*'s construction on the same lines as its predecessor, the clothing, rations, organisational structure and sledging practices from the 1875 expedition toward the North Pole were also models for the *Discovery*. Markham controlled recruitment that mostly proceeded according to his ideals (young, RN and with family heritage) and by his personal selection in many cases. The civilian scientific staff were less qualified and less experienced than their counterparts on almost every other expedition of the era. Skelton closes his *Discovery* diary with a reference to Markham: "I do believe all his actions have been more controlled by sentiment, favouritism etc. than by practical, common sense duty towards the expedition as a national undertaking" (Skelton, 2004, p. 222).

Markham's motivation for sharing so-called "confidential" notes from Scott, especially the frank commentaries on the unsuitability of Murray as a scientific leader, is unclear. Markham's acrimonious relationship with most members of the RS might have prompted this attack on Murray, who was more strongly aligned with the RS than the RGS. Markham was well connected and, being an excellent motivator and fundraiser, it's possible the expedition would never have existed except for his efforts but there is no evidence that Markham had a sufficient depth of understanding of the science that he was controlling, or of the full cycle of scientific process from planning to publication. After the tragedy of the *Terra Nova* expedition donations to the Scott memorial fund were abundant. Markham was asked to estimate the cost of working up and publishing the scientific results. He made an estimate of £13,576, but Archibald Geikie (1835-1924) questioned this value stating: "Sir Clements Markham is a bold man. He had no access to the accounts and had nothing to do with the publication of the scientific results of the 'Discovery' Expedition" (Geikie, 1913). However, as there were sufficient funds no further attempts were made to predict the expenditure and the fund allocated £15,000.

Markham failed to realise that, in the discipline of terrestrial magnetism in that era, the acquisition of new knowledge and theory was an evolutionary process, ideally founded on successful collaborations and extended observing networks operating over time. He promised revolutionary results (new theory, mariners charts) then undermined the opportunities to achieve them, and built expectations out of proportion to what could realistically have been achieved given the various circumstances that diminished opportunities for quality science.

A large volume of Antarctic history remains focused on Scott and his portrayal as either a tragic hero, or else a bungler, but this research has not been about Scott: he's an incidental player in the narrative whose core is appraisal of how science was organised and practiced. Scott had no particular aspirations towards polar exploration and was young for the level of responsibility he undertook. He acknowledged his lack of ice experience and general ignorance of exploration in correspondence with Drygalksi (Lüdecke, 2003). Scott's scholarship did not prepare him for the role of scientific directorship so he was probably at the limit of his capability in this area, and without a personal support system once south of New Zealand.

Although this research has shown some deficiency in leadership skills, some personal shortcomings and a naïve approach to scientific directorship on this first expedition, Scott is not particularly blameworthy. He was a victim of inadequate preparation for the leadership tasks. His background as an ambitious torpedo lieutenant with high career aspirations within a very structured institution never provided the opportunities to prepare for leadership in polar exploration and science. The scientific elements of the expedition would have been better served by the experience and professionalism that Professor Gregory's scientific directorship could have provided. Gregory summed up Scott's lack of preparation:

"I may as well say I do not think Scott at all a good man for the work:

1) His forte is that he is very prepossessing
2) It is his first command & for a man who talks so much about discipline I think it is a pity for his first command to be so unusual
3) I think he is a poor organiser, his departments are in arrears, & he is so casual in al his plans. He appears to trust to luck things which ought to be a matter of precise calculation.
4) He has no experience of expedition equipment
5) Instead of looking after his own work, he has apparently devoted most of his time making himself acquainted with mine: telling Koettlitz to buy microscope, getting chemical sent from abroad & not telling me even that it had come & on questions of furs, food, sledges, ski & things which are in his department his ignorance is appalling
6) He is a mechanical engineer not a sailor or a surveyor. And he does not seem at all conscious of these facts or inclined to get experience necessary.

Personally I like Scott but I am sorry he does not stick to his own work"

(Gregory, 1901a)

In terms of reputation, Scott had some lucky escapes. It would have been a major embarrassment if he returned without the ship's boats after allowing them to become buried in the ice. Matters might have been dire if anything had subsequently happened to the ship when bereft of its boats. They were only exhumed and made seaworthy after months of hard labour by crew and carpenters. Scott came very close to losing the ship, a number of times. Firstly, with the help of the *Terra Nova* rescue effort and a provident swell that broke up the sea ice, he only just averted abandoning it in the ice. Then, shortly after re-floating it, he ran aground on the shoal just off Hut Point where the ship was battered for about eight hours before she slipped off on the rising tide. Royds mentions that the ship had also grounded on the shoal on arrival (Royds, 2001, p. 337) and Scott's diary entry of 16 March 1903 indicates he knew of the shoal and its location (Scott, 1903). A week later Bernacchi described the consequence of the bilge pumps becoming blocked:

> While the water was gaining so rapidly we were actually in a sinking condition & if we had not succeeded in getting the other pump under way, as there seemed every

> probability at one time, the good ship 'Discovery' would soon have been under the briny seas of the Antarctic.
>
> (Bernacchi, 1904)

Scott might have challenged some of the omissions and deficient outcomes reported in the *Magnetic Observations* volume. It was published after the first meteorological report over which there was so much discontent. Scott was preparing for the *Terra Nova* and he would have been averse to further public debate over scientific outcomes from *Discovery,* as he was building a strong scientific program as a plank of his fundraising strategy. The reviews had glossed over or missed the deficiencies of the magnetic program on *Discovery*, so Scott probably thought it best to accept the mild criticisms without further comment. He was still at sea in a RN vessel and had been involved in an embarrassing collision with another battleship, and, although he was later found to be blameless, the matter would have been in the public mind.

What can be made of Priestley's claim that Scott was: "Before everything, a scientist…" (Priestley, 1915, p. 25). Contemporary praise of Scott as a scientist refers to the vastly more mature version of Scott on his second expedition, in spite of its stated prime objective being the trek to the geographic South Pole. His experience of overseeing the civilian staff on *Discovery* comprised his scientific apprenticeship, then the criticism of the meteorological reports showed him the need for careful performance of scientific procedures and meticulous record keeping. He had four years between expeditions during which his understanding of scientific process probably developed.

Bernacchi's interesting biography was one of the triggers for this research. He had a genuine interest in Antarctic science and as a young man was highly motivated to become proficient with skills and knowledge of value to polar expeditions as a means of joining one (Atkin, 2011). For family and business reasons he later gave up scientific work and polar travel. The overall results of the magnetic program of *Discovery* would have been a disappointment to him. He was a very competent observer and fulfilled the requirements of his position, but he did not proceed to a career as a theoretician. This was a cultural quirk of Bernacchi's family who existed as gentleman entrepreneurs, not employees. Importantly, Bernacchi's omission of the difficulties with the Lloyd-Creak circle and the errors in term hour observations during his public lectures is evidence of his loyalty to Scott, who remained a personal friend.

Bernacchi was more than a technician. He realised the importance of collecting dip and intensity observations on the Barrier journey for the better estimation of the magnetic pole location and it was his initiative to take detailed magnetic observations in the tent on the sea ice that was a master stroke, adding value to the Winter Quarters observations:

> I think that is one of the most valuable observations in the whole series, because it has really enabled us to reduce all the disturbed observations and get corrections for them. These observations are not only exceptionally valuable in themselves, but they formed a key to the final reduction of the sea observations I have mentioned, as well as those on land.
>
> (Creak, 1905)

Gregory resigned from the expedition without any sign of ill feeling. His level of professionalism is shown in his reviews of scientific work on Antarctic expeditions that were evenhanded and complimentary towards the *Discovery* (Gregory, 1908, 1909a, 1909b).

## 8.6 Institutional Failure

One important outcome of this research is the conclusion that *Discovery* could, and should have performed better in aspects of its scientific work, particularly terrestrial magnetism for which a purpose-built ship had considerable advantages over a converted whaler. The coalition between the two premier societies of England failed, and the quality and quantity of scientific output never approached its potential, especially in magnetic research. While the general public and the RGS may have viewed the expedition as a great success, the RS and the RN might have had a more reserved opinion.

The management of the expedition was characterised by a combative environment and Markham had modelled most aspects of the expedition on the Arctic expedition of 1895 and obsolete traditions of Arctic expeditions of the mid nineteenth century. There was no solid governance or management of the expedition and, in summary, institutional failures led to:

- No scientific director and a scientific leadership vacuum during preparation, operations and post-expedition management.
- Late recruitment of Bernacchi, a situation that had direct impacts on results.
- Under-preparation, insufficient training in some key areas, and failure to test vital instruments and equipment under operational conditions.
- Mis-management of funds leaving no contingency for a relief expedition or analysis and publication of results.
- Construction of the vessel to a conservative design by a shipyard without the requisite skills or access to sufficient insect-free, seasoned timber.
- Failure of collaborative arrangements in the magnetic program.

The expedition had the prospect to be the best scientific exploring expedition in history with its combination of new vessel, abundant funding, RS sponsorship and the prospective involvement of senior scientists. At the beginning, the likelihood of many of the drivers of scientific success converging in a positive way seemed very high, but many of them fell away as the preparations developed. Leadership and governance, preparations, collaborative relationships, recruitment and training, logistics and post expedition management were all deeply affected by Markham’s control.

## 8.7 Ranking the drivers of scientific success

Salveson (1998) and Hayes (1928) relied on proxies as indicators of scientific effort and most authors cited in chapter two have made generalisations about scientific success without explanation of the criteria supporting their claims, aside from quantity of scientific reports. Proxies for effort applied towards scientific outcomes include: expedition costs, number of scientists on board, length of campaign, distance travelled on scientific quests and the number of scientific publications produced. These are either indicators of potential to do science, or a measure of volume of output, but they do not account for quality and don't consider big picture outcomes such as the development of new theory or reappraisal of paradigms.

This research analysed the expedition's magnetic program in detail and according to the framework of drivers of scientific outcomes and the conclusions about whether the magnetic science achieved its potential are founded on defined criteria. None of the success drivers worked alone to create optimum outcomes and different factors operated at different stages of *Discovery's* research program, but in most stages success relied on the convergence of positive influence from a number of the drivers. Is there one driver that is pre-eminent? Yes. Successful top level organisation and leadership is the most significant factor, as it can feed to all other drivers, except that of luck. The elements that made good science in 1901 (like scientific rigour, well developed methodology, clever use of current technologies, inquisitive approaches that seek explanation to anomalies and effective communication strategies) are common to quality science today. The cycle of scientific observations, analysis and development of theory ideally ends with a foundation for predictions. None of the *Discovery* magnetic science outcomes were predictive: they were backward looking descriptions of observed phenomena in accord with the reporting standards of the day.

It's the synergy of drivers of scientific success that produce stellar outcomes of research programs. This research has demonstrated that the success drivers are closely interrelated but at the risk of presenting the analysis as simplistic, they can be tentatively ranked in order of importance into three classes: critical, contributory and peripheral. Drivers that fall into the "critical" category are those that can make or break outcomes. Governance and leadership is the most critical element influencing expedition success as nearly every driver can be influenced by management choices and organisational failures. The *Discovery* expedition results were greatly diminished by poor decisions or negligence at the management level. Insufficient funding can prevent an expedition from moving past the planning stage and bad luck can undermine scientific programs of expeditions that do succeed past that stage. Shackleton's *Endurance* (1914-1916) had a scientific program that was never realised as the ship never made a landfall and was later crushed by ice pressure. This was an example of bad luck, or possibly poor judgement, depending on your personal assessment. Recruitment and training of the scientific staff falls into the "critical" category as it has the most direct relationship to quality scientific results of any of the recognised drivers. Pre-expedition planning and preparations, then post-expedition management of data and collections can also be classed as "critical" drivers of success as these elements can influence the overall success of scientific campaigns directly.

Most of the elements selected as drivers of scientific success fall into the "contributory" category. Scientific leadership sits in this category as robust leadership fosters outcomes, although performance by individuals can overcome deficiencies in scientific leadership. Instructions are high, but not critical in importance unless the calibre of the leadership or the scientific staff is low, in which case detailed instructions about observing protocols and the performance of science are necessary. If the staff are especially proficient quality results are possible, in spite of deficient instructions. Other "contributory" factors include equipment and instruments, logistics, the work of the scientist and the social and intellectual landscapes.

The collaborative relationship with Drygalski's *Gauss* was peripheral. A successful relationship would have been icing on the cake, but none of the sponsoring institutions or individuals chose to comment on the shortcomings. Many results that are only adequate could have been more significant if the relationships for data gathering and data sharing had been better handled. The error in the term hour observations, failure to agree on a common style of reporting magnetic results and the lack of communication between data analysts after the expedition meant both the *Discovery* and *Gauss* magnetic reports missed a potential dimension in the final results.

The historic context and intellectual traditions of scientific exploring expeditions have peripheral impact on scientific outcomes, assuming that they are judged by standards of the day. On *Discovery* the paradigm was "collect and describe" and in the example of biological sciences success was measured by quantity, diversity and rarity of specimens collected and the intrinsic value is often proportional to the difficulty of collection. Modern science would assess the meaning of the collection in terms of broader contexts such as food chains, population density, genetic clines within species across gradients in latitude, interdependence between species, or evolutionary theory and fitness for purpose of organisms. In the magnetic research, *Discovery's* shortcomings were hardly mentioned in any reporting, but universal success was claimed on the strength of long run continuous records in a new locality, another allusion to results being more valuable if they are difficult to procure. This outcome was in accord with Sabine's Victorian paradigm of putting effort towards amassing data at the expense of analysis and development of theory.

No single driver of scientific success can guarantee that research program outcomes meet expectations or potential, but analysis of this ranking indicates that the elements that work together to maximise success are meticulous planning of the expedition and design of the scientific program through to publication, top calibre scientists trained to proficiency with instruments and the observing protocols and, finally, selection of an inspirational scientific leader with a heavy grounding in science who could facilitate development of a vibrant intellectual climate.

## 8.8 *Discovery's* legacies

Two iconic physical legacies remain from the *Discovery* expedition. They are the ship herself, that is the centrepiece of the Dundee Heritage Museum (Image 13), and the expedition hut on Ross Island (Image 12) that continues to be maintained by the Antarctic Heritage Trust (NZ). The scientific instruments were probably returned to the lending institutions then re-used on subsequent expeditions and museum and private collections hold many artefacts from the voyage including sledging pennants, sledges, crockery, and equipment. Shackleton burnt the magnetic observatory huts in 1909 to create a signal fire to attract attention of the *Nimrod* on his return from his southern journey (Shackleton, 1932, p. 226). From time to time the *Discovery* hut was used during Scott's *Terra Nova* expedition, then by Shackleton's Imperial Trans-Antarctic Expedition support party (1914-1917). It was not revisited until 19 February 1947 when a helicopter from the icebreaker USS *Burton Island* landed nearby (Quartermain, 1963, p. 64). The charred magnetic hut remains were photographed by the crew but have since been bulldozed. Fortunately the relative inaccessibility of Mawson's Hut at Commonwealth Bay has allowed the historically important magnetograph hut, a rare example from the era, to remain sufficiently intact to be stabilised by heritage carpenters. The absolute and transit huts did not have the protection of rocks banked against their sides and the extreme weather has taken its toll.

Image 12: *Discovery* Hut on Ross Island, 2008 (author's photo).

*Discovery* informed how science was organised and performed for later expeditions of the Edwardian era. The expedition entrenched a model of Antarctic expedition strategies that was a derivation of the RN Arctic expeditions, depending on ships for transport, an established base from which investigative parties fanned out, the availability of manpower and retention of an already dated mentality related to inefficient man haulage methods and barely used local resources. On *Discovery*, a "suggestion" book was maintained to give a place where officers and scientists could jot down ideas about improvements to gear or methods for the information of future expeditions but the fate of this useful document is unknown (Royds, 2001, p. 264).

Scott's final expedition is an example of the application of the intellectual legacies of the *Discovery*. His preparation shows he became aware of the importance of taking a superior team of scientists and he knew the risks and missed opportunities associated with keeping the exploration vessel in the far south over winter. Geikie of the RS was personally supportive of Scott's "plucky and interesting exercise" (Geikie, 1909). The plan for magnetic science owed a great deal to the heritage of the *Discovery's* magnetic program and although there was significant replication of procedures, it sought to rectify shortcomings. Scott's "Notes on the Scientific Objects of the Expedition" drafted in 1909 specify the program:

> The ship will be equipped with a gyroscopic compass and a magnetic compass can be so placed as to be comparatively free from disturbance: direct comparisons will greatly facilitate a magnetic survey to determine the declination. It may further be found possible to use a dip circle under suitable conditions for observations of inclination and force.
>
> The ship will traverse and retraverse the Ross Sea and her courses will be directed to obtain observations in the most interesting areas. Attention will be paid to the provision of expert observers.
>
> The most important magnetic work I propose for the shore parties is the repetition of the continuous magnetographs and of the absolute observations obtained by the 'Discovery' Expedition to throw light on secular and seasonal changes. In addition I hope that absolute observations may be obtained at other fixed spots and especially in King Edward VII land.
>
> Observations for declination will be made by sledge parties with improved instruments. I am especially anxious to meet the views of experts in arranging the details of this programme.
>
> (Geikie, 1909)

This plan provides a valuable insight showing that Scott intended use of improved instruments, he paid attention to acquiring expert observers, he would repeat shore party observation procedures from *Discovery* and make full use of the ship as an observing platform. This is evidence that Scott sought to rectify deficiencies from, and build upon the *Discovery* results. The science on *Discovery* also built foundation knowledge for the work of Shackleton's *Nimrod* and Mawson's *Aurora* expeditions.

Aside from the contribution to the mass of data on terrestrial magnetism there were no significant intellectual legacies for physicists. No new theories about terrestrial magnetism resulted from the research on *Discovery* and the concept of the earth as a dynamo was not proposed until years later and comprehension of the contribution of space weather to magnetic signals was only progressed substantively after the IGY.

This research has addressed questions posed in the preliminary stages. The key elements of the research question raised in section 1.5 and the location of the responses within the body of the thesis are:

- What were the indicators of scientific success in 1904? (addressed at section 7.1)
- What were the drivers of scientific success in 1904? (addressed at section 7.2)
- How adequate were planning, recruitment, preparations and training? (addressed at sections 4.4, 4.5, 4.6 and 5.1)
- How was geomagnetic science performed? (addressed at chapters 5 and 6)
- What were the *Discovery* expedition's magnetic science outcomes, how did they contribute to new knowledge in the discipline and how did each fare against the indicators of scientific success? (addressed at sections 6.9, 6.10 and 7.1)
- Was the magnetic science on the expedition a scientific success and if so, what factors contributed to that success? If not, why? (addressed at chapter 8)
- Did the *Discovery* magnetic science outcomes meet objectives and expectations, and could it have achieved more? If so, by what means? (addressed at chapter 8)

Considerable doubt has been thrown on many elements of the scientific organisation and practice of the campaign, and numerous shortcomings in the research into terrestrial magnetism and other disciplines have been revealed after a century of obscurity. The main scientific objectives for the magnetic program were potentially achievable, but not met. A large volume of magnetic data was secured and used in production of the scientific reports, but a great deal was also considered unreliable and excluded from analysis. Other data that was intended to allow review of charts for the southern oceans was never published in the scientific reports and there is no evidence of its inclusion in any published charts. The ultimate outcome of this research is a challenge to the paradigms that the *Discovery* expedition was scientifically successful and the belief that quantity of data and collections equates to success.

The intention of this research was to open a new door of scholarship in the reporting of Antarctic expedition science and this first analytical assessment of *Discovery* science according to defined parameters provides a framework for future assessments of expedition science. It made comparisons between the scientific outcomes of the expedition against stated objectives and against a suite of indicators of success relevant to the Edwardian era. It analysed the processes and outcomes of the magnetic science program on a pathfinding Antarctic expedition and concluded that success or failure in scientific and exploratory endeavours cannot be tracked to only one or two key factors. Successful voyages of scientific exploration relied on the serendipitous convergence of many factors, some outside the control or judgement of the leaders.

A practical outcome of the research is a schedule of success indicators against which to measure scientific program outputs. They were proposed, tested and shown to be of utility for researchers working in this area. An objective framework for assessment of the scientific programs of historic polar expeditions based on the elements of those programs, rather than indicators, proxies or even opinions formed from the collective contributions of prior historians and commentators is now available for future researchers. In time, as more of the holdings in the SPRI Thomas Manning archive are catalogued, then made available for public viewing, the outcomes of this research may be overturned or become less relevant. History is not a fixed record, but evolves as new material comes to light or is reinterpreted by analysis based on novel themes.

Terrestrial magnetism was a suitable test case for the suite of indicators of scientific success and for analysis, definition and rating of the drivers of success. Meteorology would also have been an ideal candidate for this research, as many elements were common to both disciplines. Both required observers trained to use specialist instruments, continuous data gathering was required at sea, on base and in the field, International collaborations were negotiated and the outputs, two years of data, were handed over to another institution for analysis and publication.

How important was the contribution to knowledge of terrestrial magnetism from the *Discovery*? Abundant observations may only translate into development of theory years after collection although at the time of collection and initial analysis they may seem unremarkable. Alternatively, after time has passed data may be considered stale and improvement in the instruments and procedures for collection may supersede the data's usefulness. The latter case is most correct for *Discovery*. After most of the expeditions of the pre-war era had returned, Bauer, possibly the world's most eminent magnetist of his time, wrote a synopsis of the state of scientific knowledge in terrestrial magnetism:

> The cause of the earth's magnetism possibly by this time, if not before, you may have said to your-selves: 'Granted that the compass needle points north and south 'because the earth itself is a magnet, what, in turn, causes the earth's magnetism, why are the magnetic poles not only not situated at the geographical poles, but not even diametrically opposite-one another, or why, instead of wandering to and fro with the lapse-of time, do, not the magnetic poles remain fixed in position?' Lest any of these questions should cause you sleepless nights, let me say that, for the present at least, it would appear the better policy to confess ignorance. We may also take comfort in the fact that if the student of the earth's magnetism has not yet discovered the true cause of his science, neither has the investigator of magnetism, in general, been able as yet to answer the question: 'what is a magnet?'
>
> (Bauer, 1914)

He then concluded with a statement that confirms that the field stalled at the empirical data collection stage in the cycle of scientific method. "The accumulation of data must at present be the chief aim of the student of the earth's magnetism."


Image 13: *Discovery* in Dundee, September 2011 (author's photo).

# Appendix I: Antarctic Expeditions: 1897-1914

| Vessel | Expedition Name | Leader | Dates | Field of Operation |
|---|---|---|---|---|
| *Belgica* | Belgian Antarctic Expedition | Adrien de Gerlache | 1897-1899 | Antarctic Peninsula and Bellingshausen Sea |
| *Southern Cross* | British Antarctic Expedition | Carsten Borchgrevink | 1898-1900 | Cape Adare, the Ross Sea and the face of the Ross Ice Shelf |
| *Discovery* | British National Antarctic Expedition | Robert Falcon Scott (R N) | 1901-1904 | Ross Sea region |
| *Antarctic* | Swedish South Polar Expedition | Otto Nordenskjöld | 1901-1904 | Antarctic Peninsula |
| *Gauss* | German South Polar Expedition | Erich von Drygalski. | 1901-1903 | Crozet and Kerguelen Islands then along the Indo-Atlantic Coastal Antarctica |
| *Scotia* | Scottish National Antarctic Expedition | William Speirs Bruce | 1902-1904 | Antarctic Peninsula |
| *Français* | French Antarctic Expedition | Jean-Baptiste Charcot | 1903-1905 | Antarctic Peninsula |
| *Nimrod* | British Antarctic Expedition | Ernest Shackleton | 1907-1909 | Ross Sea and overland towards South Pole |
| *Pourquois-pas?* | Second French South Polar Expedition | Jean-Baptiste Charcot | 1908-1910 | Antarctic Peninsula |
| *Fram* | Norwegian Antarctic Expedition | Roald Amundsen | 1910-1912 | Ross Ice Barrier and overland to the South Pole |
| *Terra Nova* | British Antarctic Expedition | Robert Falcon Scott (R N) | 1910-1913 | Ross Sea region and overland to the South Pole |
| *Kainan Maru* | Japanese Antarctic Expedition | Nobu Shirase | 1910-1912 | Ross Sea region in the first season of 1910-11, then King Edward VII Land |
| *Deutschland* | German South Polar Expedition | Wilhelm Filchner | 1911-1912 | Weddell Sea |
| *Aurora* | Australasian Antarctic Expedition | Douglas Mawson | 1911-1914 | Macquarie Island, and coastal continental Antarctica between 90° E and 158° E |
| *Endurance* and *Aurora* | Imperial Trans-Antarctic Expedition | Ernest Shackleton | 1914-1916 | *Endurance* in the Weddell Sea and *Aurora* in the Ross Sea |

# Appendix II: Chronology of magnetic science and innovation

| Date | Development | Source |
|---|---|---|
| 1581 | Norman (after 20 years at sea has established himself as chart maker and compass builder) published *Newe Attractive,* published his account of discovery of Dip, and invented the dip needle or inclinometer | Gurney, 2004, p. 61,<br>Mawer, p. 5-6 |
| 1600 | Publication of *De Magnete* by William Gilbert. He proposed that the earth is a magnet and demonstrates the distribution of magnetic inclination or dip over the earth, and over a small spherical lodestone, which he called a "terrella". Gilbert believed (incorrectly) that the terrestrial magnetic field was constant. Gilbert believed that angle of inclination would be of use to navigators for the calculation of latitude. He believed the interior of the earth was composed of iron with its magnetic energy concentrated at the poles. | Kivelson & Russell, 1995, p. 4. Mawer, 2006, p. 6, McConnell, 2005. |
| 1635 | Henry Gellibrand showed that the declination at London had reduced significantly in the previous 54 years leading to recognition of the phenomenon of secular change in declination. | Mawer, 2006, p. 7, McConnell, 2005. |
| 1639 | Henry Bond (senior) predicted correctly that the declination in London would gradually reduce to a value of zero by 1657. He proposed a simple dipole theory with the dipole precessing in a six hundred year clockwise orbit around the geographic north pole. | Jonkers, 2003, p. 85, McConnell, 2005.<br>Mawer, 2006, p. 7 |
| 1683-92 | Edmund Halley develops theory to explain variation based on four magnetic poles, two fixed on the earth's surface and two revolving on an inner nucleus of the planet, revolving with a period of about 700 years. | Mawer, 2006, p. 7 |
| 1722 | Clockmaker George Graham made a declinometer sensitive enough to show changes over the course of a day, some of which showed a diurnal cycle, and some of which showed random change. Collaborating with Andres Celcius of Sweden they showed that the diurnal cyclic changes related to local time whereas the random changes were simultaneous and independent of local time of day. Graham also realised that the time it took for the magnetic dip needle to come to rest indicated the strength of the magnetic force (intensity), resulting in the "vibration" method of determining force. | Mawer, 2006, pp. 7-9 |
| 1741 | The observations of Celsius were continued by Hiorter who made a total of over 20,000 observations on more than 1000 different days. From this data Hiorter confirmed the diurnal variation of the geomagnetic field. Simultaneous observations of strong geomagnetic activity on April 5$^{th}$ by Graham in London and Hiorter in Sweden confirms that geomagnetic and auroral activities are correlated. | Kivelson & Russell, 1995, pp. 5-6<br>Jonkers, 2003, p. 109 |
| 1785-1788 | Jean-Honoré de Lamanon, physicist on the voyage of La Perouse used a dip magnetometer with the needle suspended by a thread (reducing friction) to show that intensity increased with increasing latitude, as demonstrated by increased oscillations before settling of the dip needle at high latitudes. | Mawer, 2006, p. 10 |
| 1812 | Flinders wrote to the Admiralty with a series of experiments to be made on ships. Included is the idea of swinging the ship to obtain a round of compass bearings for deviation compensation. Admiralty agreed. The result was confirmation of Flinders' theory that the deviation was related to the direction of travel, iron on board the ship and the ship's magnetic latitude, specifically the magnetic dip. His solution was a bar of soft iron to be placed in the compass binnacle below the steering compass. | Gurney, 2004, p. 171 |
| 1817-19 | William Scoresby (Arctic whaler with an avid interest in the natural science of the Arctic) wrote a paper on his observations on the magnet taken during a whaling voyage to high latitudes in the *Esk* (1817) and read to the RS in 1819. He noted the compass sluggish, had taken measurements of variation, dip and intensity as well as making notes on deviation. He determined that most of the iron in the ship's fabric was in the vertical and that it had become magnetic by induction from the earth's magnetic field. He added to Flinders theory by proposing that the deviation at high latitudes was influenced by the vertical and horizontal | Gurney, 2004, pp. 179-181 |

| | | |
|---|---|---|
| | magnetic forces. The former becomes the stronger influence close to the magnetic pole whilst the latter becomes weaker in that locality. The soft iron can lose its induced magnetism and change polarity on crossing the magnetic equator. | |
| 1819 | The Norwegian, Christopher Hansteen published *Magnetismus der Erde* postulating that there were two principal magnetic axes, and therefore four principal points of convergence of the direction of the magnetic needle, all constantly moving. | Mawer, 2006, p. 14 |
| 1820 | Hans Oersted discovered that a conducting wire in an electrical circuit attracted compass needles. This commenced an era of hypothesis driven, laboratory experimentation, while geomagnetic specialists continued to rely on observation and inductive method. | Mawer, 2006, p. 11 |
| 1829-1835 | Humboldt arranged simultaneous observations to be made in France and Russia. This led to a network of observatories across Russia and including Sitka in Alaska and Peking. On six "term days" each year simultaneous observations were made each five minutes for twenty-four hours. This was onerous work as self-recording instruments had not yet been invented. | Mawer, 2006, p. 11 |
| 1831 | James Clark Ross established a camp at the locality of the North Magnetic Pole on the Boothia Peninsula using magnetometer and dip circle. | Mawer, 2006, pp. 3-4 |
| 1832 | Gauss "arrived at a method for measuring intensity absolutely, in units of mass, distance and time, rather than by comparison between the number of oscillations of the same needle in different locations. The observational technique devised with his collaborator, Wilhelm Weber, involved counting oscillations, as before, then using the dipping needle to deflect the compass needle." | Mawer, 2006, p. 12 |
| 1834 | Weber and Gauss opened an observatory in Göttingen that became responsible for coordinating term days and collecting and publishing observations. The Göttingen Magnetic Union resulted from the collaboration. | Mawer, 2006, p. 12 |
| 1838 | George Airy, Astronomer Royal used magnets to successfully correct compass deviation on the *Rainbow* after swinging the ship in the basin at the Deptford victualling yards at Greenwich. This was followed by his engagement to carry out the same procedure for *Ironsides*, the first iron-hulled sailing ship. | Gurney, 2004, pp. 200-203 |
| 1838 | Gauss used Sabine's data to determine mathematical formulae to describe earth magnetism and predicted the magnetic poles would be at 77° 84' N, 296° 30' E and 77° 8' S, 116° 30' E. Published as *Allgemeine Theorie des Erdmagnetismus* it also postulated that nearly all normal magnetic force came from the earth but daily, seasonal and irregular disturbances were probably cosmic in origin. | Turner, 2010, pp. 122-123, McConnell, 2005, p. 353. |
| 1850 | Sunspot measurements over a period of 25 years by Heinrich Schwabe allow him to deduce that the variation on the number sunspots is periodic, with a period of about 10 years. | Kivelson & Russell, 1995, p. 6 |
| 1851 | Richard Carrington spots a great flare of white light on the sun while sketching sunspots, a phenomenon confirmed by a second observer some distance away. At this moment, the Kew observatory's measurements of the magnetic field had been disturbed. Finally, 18 hours later, one of the strongest magnetic storms ever recorded broke out. Auroras were seen as far south as Puerto Rico. It is concluded that the disturbance would have to be moving at over 2 300 km/s. | Kivelson & Russell, 1995, p. 6 |
| 1896 | Journal *Terrestrial Magnetism* came into existence under editorship of Louis Bauer, who had a doctorate on the secular variation of geomagnetism. | McConnell, 2005, p. 357. |
| 1902-03 | Kristian Birkeland concludes after his third expedition that large electric currents flowed along the magnetic-field lines during aurorae. | Kivelson & Russell, 1995, p. 7 |
| 1909 | Mawson, David and MacKay arrived at locality of South Magnetic Pole at 72° 25' S, 155° 16' E. on 16 January. | Shackleton, 1932, p. 310 |
| 1912 | Bage, Webb and Hurley of Mawson's Australian Antarctic Expedition again sledge to the south magnetic pole determining it to be at 71° 10' S, 150° 43' E., meaning that in 1909 Mawson may have missed it by about 130 kilometres. | McConnell, 2005, p. 357. |

# Appendix III: Specifications for construction of *Discovery's* magnetic observatory

**Appendix III, Item 1:**

Preliminary notes on the requirements for the magnetic observatory during *Discovery's* construction are found in handwritten form authored by Captain Creak, whose name appears on the back of the document in Markham's distinctive handwriting (Creak, n.d.b).

<u>Antarctic Expedition 1899</u>

If successful magnetic observations are to be made over the large water areas in a ship the following items in her construction should be attended to-

1 Vessel to be built entirely of wood & propelled by steam.

2 No iron or steel to be used in the structure of the ship.

3 It is suggested that phosphor bronze should be largely used where steel is generally employed

4 The engines to be far aft, leaving the centre of the vessel free for the magnetic instruments

5 <u>On no account</u> should any iron or steel be fixed within 30 feet of the place selected for the magnetic observations

6 If any iron or steel is concealed in the ship's structure, the magnetic instruments will find it out & suffer accordingly –

7 It is absolutely necessary that no iron or steel should be used in the vessel which would cause a vertical magnetic force at the observing station. Horizontal forces can be eliminated in a great measure by swinging the ship, the vertical force cannot.

**Appendix III, Item 2:**

The following is quoted directly from the lecture notes for the ship constructor's lecture to the Forty-sixth Session of the Institution of Naval Architects (Smith, 1905):

The fitting of a magnetic observatory was one of the special features of the design. In addition to making satisfactory arrangements for the Standard Compass for the proper and safe navigation of the vessel, which was in itself a difficult matter for a vessel about to penetrate such very high latitudes, it was necessary to make a special house for the purposes of a magnetic observatory, warmed by non-magnetic lamps, in which it would be possible for an observer, with a fair amount of personal comfort, to make the magnetic observations constituting such a prominent feature of the work of the expedition.

The construction of the observatory is fully dealt with in Clause 31 of the Specification. The work done in this observatory was of enormous magnitude and of great value. The observations made are being analysed and systematically dealt with by Captain Chetwynd, the present Admiralty Superintendent of Compasses, and will, in due course, be made public for the information of navigators and all others interested in magnetic phenomena in high southern latitudes. It is no part of the present paper to go into this matter, beyond describing the magnetic circumstances relating to the location of the observatory; but it may be of interest to state that the condition that there be no magnetic metals within a radius of 30 ft. Of the magnetic observatory had very far-reaching effects. For instance, the main shrouds had to be hemp cordage, and the shrouds were set up by hemp lanyards rove through the old fashioned wood dead-eyes, so familiar in the days of their youth to the older members present among us.

**Appendix III, Item 3:**

The following is Clause 31 of the ship construction specifications for *Discovery* quoted in full in Smith, 1905:

**Specifications for Magnetic laboratory**

A magnetic observatory is to be constructed and fitted where shown on the upper deck to receive a magnetic pedestal instrument which will be provided by the President. This instrument is to be firmly secured to the deck by the contractor, who is to provide all necessary fastenings for the purpose.

The magnetic observatory is to be very fully lighted from the top by means of the special pattern illuminators referred to under cabins and cabin fittings. Cowls are also to be provided for ventilation; side illumination is not required.

The following fittings are to be provided and fitted in the magnetic observatory, viz.:-

A writing desk, with drawers underneath; an observing stool with long legs; ample bookshelf accommodation; a copper or brass warming lamp, mounted low down in gimbals.

The sides, door and roof of the magnetic observatory are to be lagged with 1½ inch woven asbestos, secured with ½ inch fir matchboarding.

An 1½ inch well-lagged copper voice pipe is to be led from the standard compass to a convenient place inside the magnetic observatory. This pipe is to have a large bell-mouth at each end, so as to admit of easy conversation and to avoid the necessity of whistling. A water tight cover to be provided at its upper end to prevent the passage of water when the pipe is not in use.

Stowage is to be provided outside the magnetic observatory for magnetic instruments, and preferably 30 ft. from it although this is not essential. The stowage will involve cupboard and drawer accommodation of 2ft. deep by 5ft. by 5 ft. frontage. All this stowage accommodation may be of light dry fir.

The laboratories on the upper deck are chiefly intended for the reception and examination of specimens dredged up from the bottom of the sea.

They are to be fitted with a large sink, provided with ample drainage, and with numerous shelves and racks for the reception of bottles of various sizes to receive specimens. Desks and sitting accommodation are to be provided. Side lights are to be provided as indicated in the profile, and ample overhead lighting is also to be provided. These laboratories are to be lagged and warmed as described for the magnetic observatory. Details of the required fittings will be furnished by the overseer on application when necessary to proceed with the work.

The magnetic observatory and the laboratories on the upper deck are to be constructed of 2 inch teak, well tongued with brass tongues, and secured in the most efficient manner, so as to be capable of withstanding very severe blows from the sea. Brass stay rods, and all other necessary securities, are to be freely used to secure this object.

(Smith, 1905)

# Appendix IV: Schedules of magnetic instruments

### Appendix IV, Item I.

The following list is from a schedule attached to October 1900 correspondence between Macgregor of the Admiralty and Longhurst, secretary to the *Discovery* expedition:

> "Standard Compass Binnacle patt. 47a, Compass pat. 14. with metal brackets.
>
> Steering Compass Binnacle pattern 47a, Two, patt.14 Two
>
> The cards of the above compasses have a period as follows
>
> Card No. 1, 25 secs.
>
> Card No 2, 15 secs.
>
> Azimuth mirror of size suitable for compass, patt 14 same value as Pattern 56…. 2 no.
>
> Boat's Compasses liquid — Compasses patt 20, specially constructed to avoid liquid freezing…2 No.
>
> Note :- The binnacles compasses, and azimuth mirrors will have small modifications from the ordinary service pattern as shown above to fit them for Antarctic service.
>
> Following to be supplied from Deptford:

| | | | |
|---|---|---|---|
| Spheres, | patt. | 59 | Two pairs |
| Flinders bars, | patt | 45, | Two sets |
| | Patt | 54 | 15 No. |
| Magnets, | patt | 55a. | 40 No. |
| | Patt | 55b | 10 No. |
| Covers, spare, | 53c | | 2 No. |

(McGregor , 1900)

**Appendix IV, Item II.**

The following list of magnetic instruments for research and navigation is from the booklet *List of Instruments Provided*, (n.d.).

| | |
|---|---|
| Fox Dip and Intensity Apparatus | 3 |
| Dip and Intensity Apparatus, with Lloyd's needles | 2 |
| Compass for Magnetic Observatory | 1 |
| Horizontal vibration needle, in case | 1 |
| Vertical Vibration needle, with circle | 1 |
| Fox Gimbal table for magnetic observatory | 1 |
| Special Standard Compass, with spare gear | 1 |

| | |
|---|---|
| Unifilar Magnetometer, for Absolute Horizontal Force and Declination | 2 |
| Barrow's Dip Circle, for absolute inclination, fitted with Lloyd's needles for total force | 2 |
| Instruments, for observing the diurnal Variation of all three magnetic elements | 2 |

CHRONOMETERS

| | |
|---|---|
| Box | 5 |
| Pocket | 3 |
| Deck Watches | 4 |

COMPASSES, ETC

| | |
|---|---|
| Bowls | 3 |
| Boats | 6 |
| Landing Compass | 1 |
| Mirrors (Azimuth) | 2 |
| Cards | 6 |
| Prismatic | 3 |
| Pocket | 3 |

**Appendix IV, Item III.**

The following list of magnetic instruments for research (not navigation) from the opening of the *Physical Observations* volume:

Two Unifilar Magnetometers, Nos. 25 and 36, by Elliot Bros.

Two Inclination Circles, Nos. 26 and 27, by Dover.

Two Lloyd-Creak Circles, Nos 143 and 149, by Dover.

Two Fox Circles, Nos. 28 and 29, by Dover.

One set of Eschenhagen Magnetographs.

(Chetwynd, 1908, p. 133)

# Appendix V: Magnetic observation data sheets

**Appendix V, Item I.**

Christchurch, 16 December 1901, Dip by Lloyd-Creak Circle # 149

**Appendix V, Item II.**

Christchurch, 16 December 1901, Total Force by Lloyd-Creak Circle # 149

**Appendix V, Item III.**

Christchurch, 5 December 1901, Kew Pattern Magnetometer (Elliot # 25) Deflection

L. C. Circle 149



## MAGNETIC DIP.

STATION Christchurch Observatory Date 16th of Decr. 1901.

Circle No. ______ Needle No. 2A

Setting of Azimuth Circle 79° 35'

Remarks

Time 11·50 to 11·55 AM | 4·55 to 5-15 Pm.

| Face of Needle | Face of Instr. | Poles direct B dipping: Lower end | Upper end | Mean | Poles reversed A dipping: Lower end | Upper end | Mean |
|---|---|---|---|---|---|---|---|
| Face of Needle to face of Instrument | EAST | 67. 40 | 67. 41. | 67, 40·5 | 67. 42 | 67. 43 | 67. 42·5 |
| | | 40 | 41. | 40·5 | 42. | 43. | 42·5 |
| | | Mean = a = | | 67, 40·5 | Mean = b = | | 67. 42·5 |
| | WEST | 67. 46 | 67. 45. | 67. 45·5 | 67. 47 | 67, 47 | 67, 47·0 |
| | | 43 | 43. | 43·0 | 46 | 45. | 45·5 |
| | | Mean = a′ = | | 67. 44·75 | Mean = b′ = | | 67, 46·25 |
| Face of Needle reversed | WEST | 67. 47 | 67. 47. | 67. 47·0 | 67, 45 | 67. 44. | 67, 44·5 |
| | | 47 | 48 | 47·5 | 44 | 44 | 44·0 |
| | | Mean = a″ = | | 67. 47·25 | Mean = b″ = | | 67. 44·25 |
| | EAST | 67. 40 | 67. 39 | 67. 39·5 | 67. 41 | 67. 41 | 67. 41 |
| | | 39 | 38 | 38·5 | 40 | 40 | 40 |
| | | Mean = a‴ = | | 67, 39·00 | Mean = b‴ = | | 67. 40·5 |
| | | a″ | | 47·25 | b″ | | 44·25 |
| | | a′ | | 44·25 | b′ | | 46·25 |
| | | a | | 40·50 | b | | 42·5 |
| | | Sum | | | Sum | | |
| | | Mean of Means = α | | 67, 42·75 | Mean of Means = β | | 67, 43·37 |
| | | | | | Do. do. α | | 67, 42·75 |

Observer Louis Bernacchi

$\frac{\alpha+\beta}{2}$ = Dip = 67° 43′·06

E (3)16463. 300.—4/01. Wt. 339. E. & S.

L. C. Circle 149



# TOTAL MAGNETIC FORCE (SEA).

STATION Christchurch Observatory Lat. 43° 31′ 50″ S Long. 172° 38′ 9″ E.
Date 16th Decr 1901. Time commencing 4 . 15 ending 4 . 25 Pm.
Therm. 19.5 C Remarks
Setting of Azimuth Circle 79° 35′ Ship's Head

Statical Needle No. 4. Wright No 4.

| Face of needle to face of instrument | Face of Instr. | North end | South end | Mean |
|---|---|---|---|---|
| | East | 49. 44 | 49. 44 | 49. 44 |
| | | 45 | 45 | 45 |
| | | 45 | 44 | 44.5 |
| | | Mean = $\eta'$ | | 49. 44.5 |
| | West | 49. 54. | 49. 55 | 49. 54.5 |
| | | 54 | 55 | 54.5 |
| | | 55 | 56 | 55.5 |
| | | Mean = $\eta''$ | | 49. 54.83 |
| Face of needle reversed | West | 49. 40 | 49. 40 | 49. 40 |
| | | 39 | 39 | 39 |
| | | 39 | 40 | 39.5 |
| | | Mean = $\eta'''$ | | 49. 39.5 |
| | East | 49. 50 | 49. 50 | 49. 50 |
| | | 50 | 50 | 50 |
| | | 49 | 49 | 49 |
| | | Mean = $\eta''''$ | | 49. 49.67 |
| | | $\eta'''$ | | 39.5 |
| | | $\eta''$ | | 54.83 |
| | | $\eta'$ | | 44.5 |
| | | Mean = $\eta$ | | 49. 47.12 |
| | | Dip = $\theta$ | | |
| | | Deflection = $\theta - \eta = u$ | | |

Deflection of Dipping Needle No.
by Statical Needle No.
Face of Instrument to East
Faces of both needles to East
North end of deflecting needle next to tangent screw

Readings of Deflected Needle

| | North end | South end | Mean |
|---|---|---|---|
| N. end of deflector to North | 79. 10 | 79. 9 | 79. 9.5 |
| | 10 | 9 | 9.5 |
| | 8 | 9 | 8.5 |
| | Mean. | | 79. 09.17 |
| N. end of deflector to South | 33. 24 | 33. 27 | 33. 25.5 |
| | 24 | 27 | 25.5 |
| | 23 | 25 | 24.0 |
| | Mean. | | 33. 25.00 |
| | Difference | | |
| | Half-difference = $u'$ | | |

Face Outwards.

Calculation

Cos $\eta$, Log =
Sin $u$, Log =
Sin $u'$, Log =
Sin $u$ Sin $u'$, Log =
2 /
$\sqrt{\dfrac{\text{Cos }\eta}{\text{Sin }u\text{ Sin }u'}}$ Log =
A Log =
R = Log =

$$R = A\sqrt{\frac{\text{Cos }\eta}{\text{Sin }u\text{ Sin }u'}}\text{; where } A = \frac{X}{\text{Cos }\theta}\sqrt{\frac{\text{Sin }u\text{ Sin }u'}{\text{Cos }\eta}}$$ as observed at the Base Station.

Observer Louis Bernacchi

E (3)16465.—1. 300.—4/01. Wt. 339. E. & S.

Magnetometer No 25, Elliott



## OBSERVATIONS OF DEFLECTION.

STATION Christchurch Obs: Lat. 43° 31′ 50″ S Long. 172° 38′ 9″ E.

Mean Time at Station: commencing 11· 24 Am. , ending 11· 49 Am. .

Magnet ( 25 D ) deflecting; ( 25 C ) suspended. One Div. of Scale = ″

| Deflecting Magnet. Distance in Cms. | N. End. | Temp. | Readings of Verniers. | Scale Reading. | Correction to Middle of Scale. | Mean of Verniers. | Corrected Circle Reading. | Means and Differences. | |
|---|---|---|---|---|---|---|---|---|---|
| | | ° | ° ′ ″ | Div. | ′ ″ | ° ′ ″ | ° ′ ″ | ° ′ ″ | |
| EAST | | | | | | | | | |
| 30 | E. | 23·8 | 328, 34, 20<br>148, 34. 00 | 20 | | 328. 34. 10 | | 328, 47. 15<br>295. 8. 50 | |
| 40 | W. | 24·1 | 304. 52. 40<br>124, 52, 00 | | | 304, 52, 20 | | 33, 38. 25 | Diff. |
| 40 | E. | 24·1 | 318. 54. 40<br>138, 54. 10 | | | 318, 54. 25 | | 16. 49. 12 | $u$ |
| 30 | W. | 24·2 | 295, 02, 40<br>115, 02. 00 | | | 295. 02. 20 | | | |
| WEST | | | | | | | | | |
| 30 | W. | 24·5 | 295. 15, 40<br>115, 15. 00 | | | 295. 15. 20 | | 318. 59. 13<br>304. 55. 25 | |
| 40 | E. | 24·6 | 319. 04. 20<br>139. 04. 00 | | | 319. 04. 10 | | 14. 03 : 48 | Diff. |
| 40 | W. | 24·8 | 304. 58. 40<br>124. 58. 20 | | | 304. 58. 30 | | 7. 01. 54 | $u'$ |
| 30 | E. | 25·0 | 329. 00. 40<br>149. 00. 00 | 20 | | 329. 00. 20 | | | |
| Mean $t$ = | | 24°·4 | Observed Angles of Deflection $r_o$ = 30 ; $u$ = 16. 49. 12 ; $r'_o$ = 40 ; $u'$ = 7. 01. 54 | | | | | | |

$$\frac{m_o}{X_o} = \tfrac{1}{2} r^3 \sin u ; \quad \frac{m'}{X'} = \frac{m_o}{X_o}\left\{1 + \frac{2\mu}{r_o^3} + q(t - t_o) + q'(t - t_o)^2\right\} ; \quad \frac{m}{X} = \frac{m'}{X'}\left(1 - \frac{P}{r_o^2}\right).$$

| | $r_o$ = 30. | $r'_o$ = 40. |
|---|---|---|
| $1 + \frac{2\mu}{r_o^3} =$ | 1·00045 | 1·00019 |
| $+ q(t - t_o) + q'(t - t_o)^2 =$ | ·01376 | ·01376 |
| $1 + \frac{2\mu}{r_o^3} + q(t - t_o) + q'(t - t_o)^2 =$ | 1·01421 | 1·01395 |
| $1 - \frac{P}{r_o^2} =$ | 1·00662 | 1·00373 |

| | $r_o$ = 30 | $r'_o$ = 40 |
|---|---|---|
| $\frac{1}{2}r^3$ Log. = | 4·13046 | 4·50538 |
| $\sin u$ Log. = | 9·46145 | 9·08784 |
| $\frac{m_o}{X_o}$ Log. = | 3·59191 | 3·59322 |
| Log. = | ·00613 | ·00602 |
| $\frac{m'}{X'}$ Log. = | 3·59804 | 3·59924 |
| Log. = | ·00287 | ·00162 |
| $\frac{m}{X}$ Log. = | 3·60091 | 3·60086 |
| $mX$ Log. = | 2·31342 | 2·31342 |
| $mX \div \frac{m}{X} = X^2$ Log. = | $\bar{2}$·71251 | $\bar{2}$·71256 |
| $X$ = ·22712 Log. = | $\bar{1}$·35625 | $\bar{1}$·35628 |
| $mX \times \frac{m}{X} = m^2$ Log. = | 5·91433 | 5·91428 |
| $m$ = 906·05 Log. = | 2·95716 | 2·95714 |

Observer Louis Bernacchi

Values by Magnetometer No NABC (Jones) of Christchurch N.Z. $X$ = ·22719 $m$ = 645·90 Time 11-57 Am. Dec 5th

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